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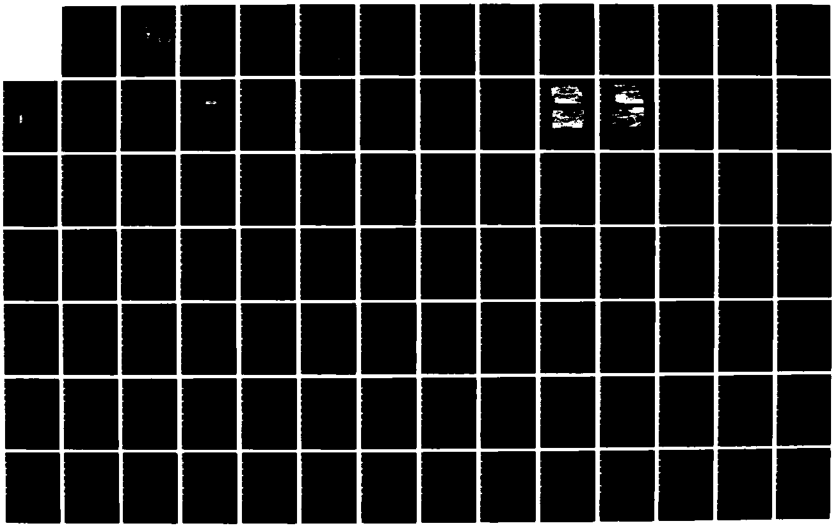

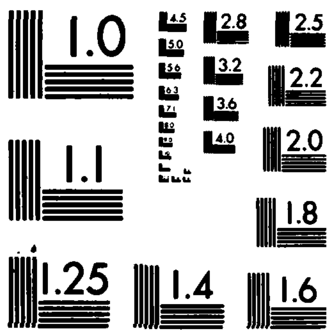

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NAVAL POSTGRADUATE SCHOOL
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THESIS

NON-LINEAR TRANSIENT RESPONSE
OF FLAT PLATE TO AIR SHOCK WAVE

by

Lee, Jae-Nam

December 1983

Advisor: Y. S. Shin

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NON-LINEAR TRANSIENT RESPONSE OF FLAT PLATE TO AIR SHOCK WAVE

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

The non-linear elasto-plastic response of a clamped flat plate to a typical air shock wave were investigated. The nonlinear effects to the plate responses due to the material and geometric nonlinearity were studied.

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I. INTRODUCTION

Conventional tanks (old tanks) which have steel armor, can be completely defeated by one round of modern projectiles such as anti-tank missiles. That has been proved in the 1973 Arab-Israeli war. In that war, the 40% of total Israeli casualties were caused by armored vehicle destructions. Thus, tank armor improvement became the first priority in the Israeli tank corps.

If war occurs in any country, the same problem will be faced. That is the reason why the modification of the conventional tank armor is needed against modern anti-tank weapons. To improve the armor protection, the material properties, projectile characteristics, and explosion phenomena must be understood well. This is a complicated and difficult problem and is originally a nonlinear problem.

First the shock wave from an explosion imposes a dynamic load on any object. That dynamic load is characterized by rapidly reached peak overpressure which then decreases as the shock wave decays. The net effects of the load depend both on the nature of the shock wave and the geometry and construction of the object. For example, if the explosion occurs on thin skirting plate, perforation takes place by impact load and their impulse loading for main armor would be reduced significantly. The typical air shock wave was characterized

as follows; the shock wave is supersonic and generates the abrupt increasing overpressure.

The non-linear elasto-plastic responses of a clamped flat plate to a typical air shock wave were investigated. The nonlinear effects to the plate responses due to the material and geometric nonlinearity were studied.

In this study, (1) the necessity of the modification of old armored vehicles was reviewed, (2) the NASTRAN code was employed, (3) the theoretical background of the nonlinear transient analysis was described, (4) a step by step procedure of analyzing the dynamic load problem by shock wave using NASTRAN code was developed, and (5) sensitivity analyses were performed and also difficulties associated with the nonlinear analysis were described.

II. LITERATURE REVIEW

A. MODERN PROJECTILES

An important version of the AP (Armor-Piercing) round is that known as APDS (Armour Piercing Discarding Sabot). In this round the armour-piercing element is a hard core of calibre significantly smaller than that of the complete projectile and shaped for maximum anti-armour effectiveness. This is surrounded by a much lighter casing, or sabot, which breaks up as the projectile leaves the gun barrel. The point of this arrangement is that the core can have a shape which differs considerably from that of the complete projectile and, not having been scored by the rifling in the barrel, is aerodynamically clean. Moreover, since it is very much heavier than the sabot, the core acquire a greater energy than could be imparted to it if it were fired, without sabot, by a gun of appropriate calibre and the same chamber pressure as that of the larger gun. A controversial refinement involves the use of depleted uranium in the core. This metal has an exothermic reaction with steel which aids penetration; it is controversial because of its connection with the other isotopes of uranium and their radioactive properties.

High explosive (HE) rounds with contact fuzes can also be used against tanks and may, if they are large enough, be

effective against exposed portions of the tank mechanism (such as the tracks) but will not in general be effective against heavy armour. Two modern refinements of the HE round may be effectively used in some circumstances: they are the HEAP (High-Explosive Armour Piercing) and HESH (High-Explosive Squash-Head) rounds.

The HEAP round has a projectile of relatively high velocity, a hardened case and a high-explosive charge which is contact fuzed with a very short delay. The effect of the arrangement is that the projectile either embeds itself in the armour or passes through it and then explodes with an effect which is more damaging than that of the simple HE round.

HESH rounds can be used with lower-velocity weapons, and are so designed that the nose of the shell crumples on impact to make a large contact area before the explosive is detonated. Such rounds will not, in general, pierce armour, but the explosion sets up shock waves in the armour which in themselves can incapacitate the crew and may also cause pieces of metal to break away from the surface remote from the explosion. Such fragments fly off at high velocity and can do great damage inside a tank turret.

Most widely used in infantry weapons, however, is the projectile (which may be a shell, a rocket, a grenade or a guided missile) with a shaped-charge warhead frequently described as a HEAT (High Explosive Anti Tank) round. This

type of projectile is designed to be effective with only a moderate impact velocity and depends for its effect on the design of the warhead and is formed round a hollow cone with its apex to the rear. The base of the cone is of approximately the same diameter as the warhead at that point and in front of it is an air space enclosed by the rounded or pointed head of the projectile on which the fuze igniter is mounted. The operation of the fuze is critical to the success of the charge. It has to have a set distance from the surface of the armour when it is detonated and for this reason the igniter is carried well in front, often giving rise to the distinctive pointed nose of a hollow charge round.

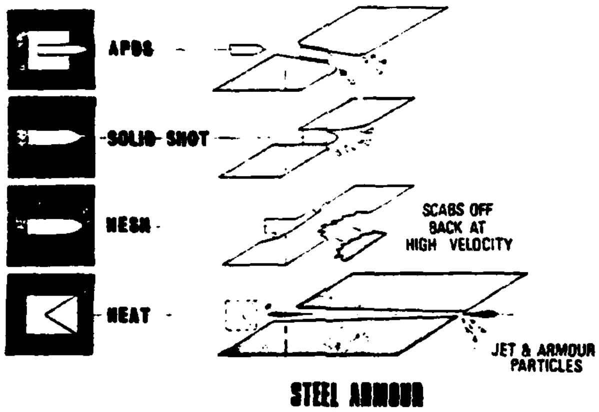


Figure 2.1. The Effects of Current Anti-Tank Projectiles on the Steel.

The igniter is connected to the detonator which is at the back of the charge, this starts a detonation wave running through the conical explosive and the result is that the force of the explosion is concentrated into a thin jet

moving at a speed of over 20,000 m/s and at a great temperature. The jet takes a finite distance to form, hence the importance of having the igniter in front and the distance required to form a jet is known as the "stand off". For most modern warheads the stand off distance needs to be between 2 and 3 diameters of the warhead and to provide the full distance sometimes interferes with the ballistics of the projectile.

The effects of a hollow charge on the interior of a vehicle can be variable. A very small jet may well not cause much damage apart from making a hole in the armour and destroying whatever is in its direct path, but it is possible to "turn" warheads so that the penetrative effect is lessened but there is more energy left after passing through the armour and this energy can be spread out into more of a fan-shaped exit blast with appropriately enhanced damage. All hollow charge jets carry a certain amount of molten metal into the interior and some research has gone into finding ways of carrying more through the hole.

Two examples of the Soviet anti-tank guided missiles are described below. [Ref. 1]

1. <u>Sagger Anti-Tank Guided Missile</u>

Sagger is the NATO code-name for the Soviet anti-tank missile which is also known by the US alphanumeric designation AT-3, which is now extensively deployed in Europe and elsewhere. Currently it is known to be used in at least three ways:

a) As a man-portable missile

b) Mounted on a bracket

c) Mounted on a vehicle

The characteristics of sagger missile is as follow.

a) Type: Wire-guided MCLOS (Manual Command to Line of Sight)

b) Weight at launch: 11.3 kg

c) Diameter: 120 mm

d) Warhead: HEAT

e) Range: 500-3000 m

f) Penetration: 400 mm

2. <u>AT-4 Anti-Tank Guided Missile</u>

There have been reports for some years of a Soviet SACLOS (Semi-Automatic Command to Line of Sight) system, but it was not until 1980 that photographs and a little information appeared in some Warsaw Pact military journals.

Characteristics:

a) Type: Wire guided SACLOS system

b) Weight at launch: 40.4 kg

c) Diameter: 120 mm

d) Warhead: HEAT

e) Range: 2000 - 2500 m

f) Penetration: 500-600 mm

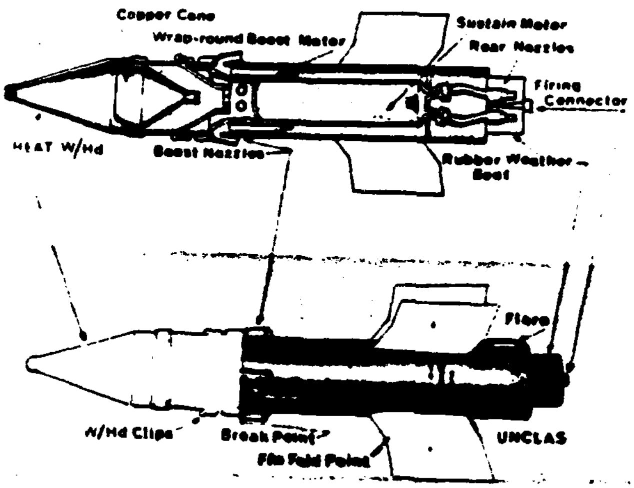


Figure 2.2. Sectioned View of Sagger Missile.

Which of these various types of projectile will be most effective against armour which depends on the design and thickness of the armour. Against solid armour the HEAT round is particularly effective; but in certain circumstances a sandwich construction is likely to be more vulnerable to an APDS round. There is therefore a good deal to be said for having a mix of projectiles available for satisfactory defense against tanks.

B. CONFIGURATION OF ARMORED VEHICLES

1. Armor

We can define the military armor as a material intended to protect men and installations of equipment.

Aluminum, titanium and magnesium alloy, plastic laminates, nylon fabrics and masticstone composites have all been used, but the most common form of armor is heat-treated alloy steel. This comes mainly in two forms: homogeneous and face-hardened.

The first has constant ballistic and mechanical qualities throughout, which in modern tank armor means high tensile strength (of the order of 150,000 lb sq in) and medium hardness (i.e. Brinnell N 300); face-hardened armor consists of a very hard first layer which resists penetration but lacks toughness and a more elastic core to support the face. Naval deck armor and modern tank armor are homogeneous, while face-hardened armor is still used for some light armored vehicles and side protection for naval vessels.

Steel armour usually means rolled or wrought plates, but castings are used for tank turrets and even for entire tank hulls, as in the M.48 and M.60 tanks (Steel armor is usually a nickel-chrome-molybdenum alloy, but other alloys including manganese-silicon-chromium-nickel steel have been used, especially in Soviet tank armor.).

Typically, a well-designed hollow-charge warhead can be expected to penetrate armor up to five times the diameter of the warhead. The best defense against such attack is not to make thicker armor, but to dissipate the jet before it reaches the surface. To do this a light screen is carried some distance in front of the main armor, of sufficient thickness to set off the fuze of any hollow-charge projectile.

Quite naturally such screens do not last long, but they are easily replaced and provide almost complete protection for the armor behind. A common use of such a technique is the thin skirting plates carried over the tracks of all modern tanks. Before leaving this subject it is appropriate to mention a recent British armor development, the 'Chobham'

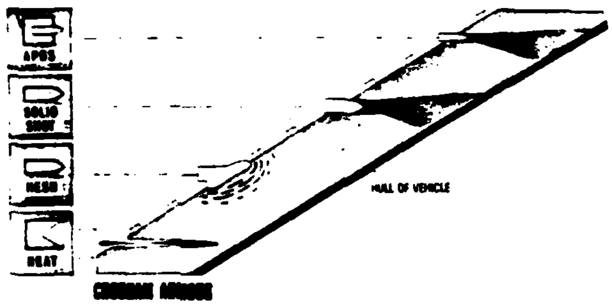


Figure 2.3. The Effect of Anti-Tank Projectiles on "Cobham" Armor.

armor. This is claimed to offer greatly enhanced resistance to all forms of projectile as is indicated by the accompanying illustrations. Details of the construction of this armor have not been released, but it seems probable that it is a sandwich made up of two sheets of armor plate separated by a highly dispersive, possibly granular, filling. The disadvantage of this armor lies in its bulk. To gain the protection, it has to be thick and fairly heavy; tanks are already large enough and the addition of armor plating, which is 200 mm or more in thickness makes a startling difference to the outline and bulk of the entire vehicle.

2. Current Modification of Old Tanks

Determining which one should we choose, a new one or modification of an old one usually depends on cost and political situations.

The U.S. completed conversion of M48 tanks to M48A5 standards in 1980. This conversion basically included adding diesel engines to M48A1s and adding 105-mm guns to the turrets of M48A1s and M48A3s. Numerous minor changes were also made. But little improvement in armor protection has been made. If we want to take more modifications for M48A3s and M48A5s tanks, a spaced applique armor should be added and include a 1,200 hp engine, improved transmission, better fire control, and a hydropneumatic suspension system.

The following example shows modern modifications.

The High Performance M60 MBT has been developed as a private venture by the General Products Division of Teledyne Continental Motors. It is essentially an M60 series MBT fitted with a new powerpack, new suspension and, as an option, additional armor. These modifications can be carried out on existing M60 series. Teledyne believes that to fit an M60A1 with the new powerpack would cost under $200,000, while the added armor would cost just $40,000.

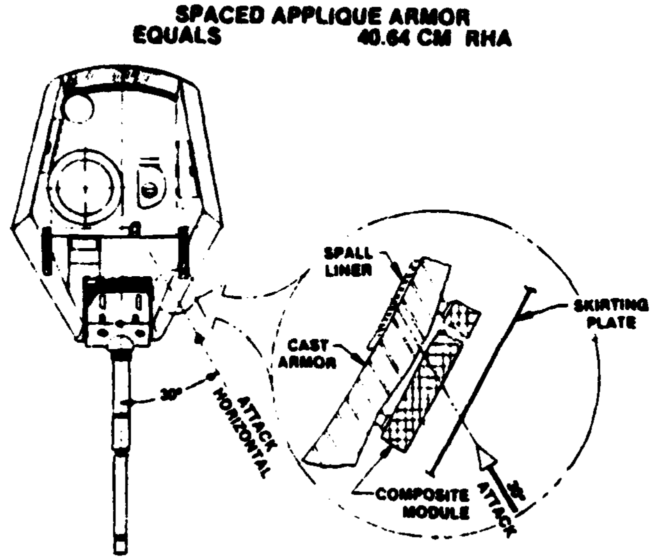


Figure 2.4. Applique Armor in M60 MBT.

3. <u>Israel Add-On Armor</u>

Israeli experience in the 1967 campaign proved that mobility was not substitute for armor protection and they therefore decided at an early stage that the main emphasis would be placed on armor, with firepower and mobility second and third priorities. After that they spent a lot of money to figure out this protection problem. Total cost of research, development, trials and the building of the prototype vehicles was about $65 million.

In May 1977 Israel finally announced that it had developed a new MBT called the Merkava which was made of

cast and welded armor with a well-shaped glacis plate. Behind the first layer of cast armor is a space filled with diesel fuel and then another layer of armor. This spaced armor gives the tank protection from HEAT projectiles and ATGWs (anti-tank guided weapons).

They also modified their old tanks such as M60s, Centurions, etc.

The add-on and readily detachable protective arrays seen on Israeli M60s and Centurions contain ceramic tiles, would also mark a first in terms of operational deployment. The possibility cannot be excluded that armor of both kinds is involved.

While no answers are to be found in external appearance, the configurations, as seen in the accompanying Defence Attache photographs, show obvious differences in the thickness and shape of the packs provided for M60 and Centurion respectively. The Centurion's additional armor is mainly in the form of quite shallow panels fitted to the brow of the turret and thicker pieces to the glacis and the mantlet either side of the main gun; a hole is included in the left-hand piece to permit the firing of the coaxial machine gun. Wedge-shaped packs are mounted on top of the storage boxes fitted forward above the track guards.

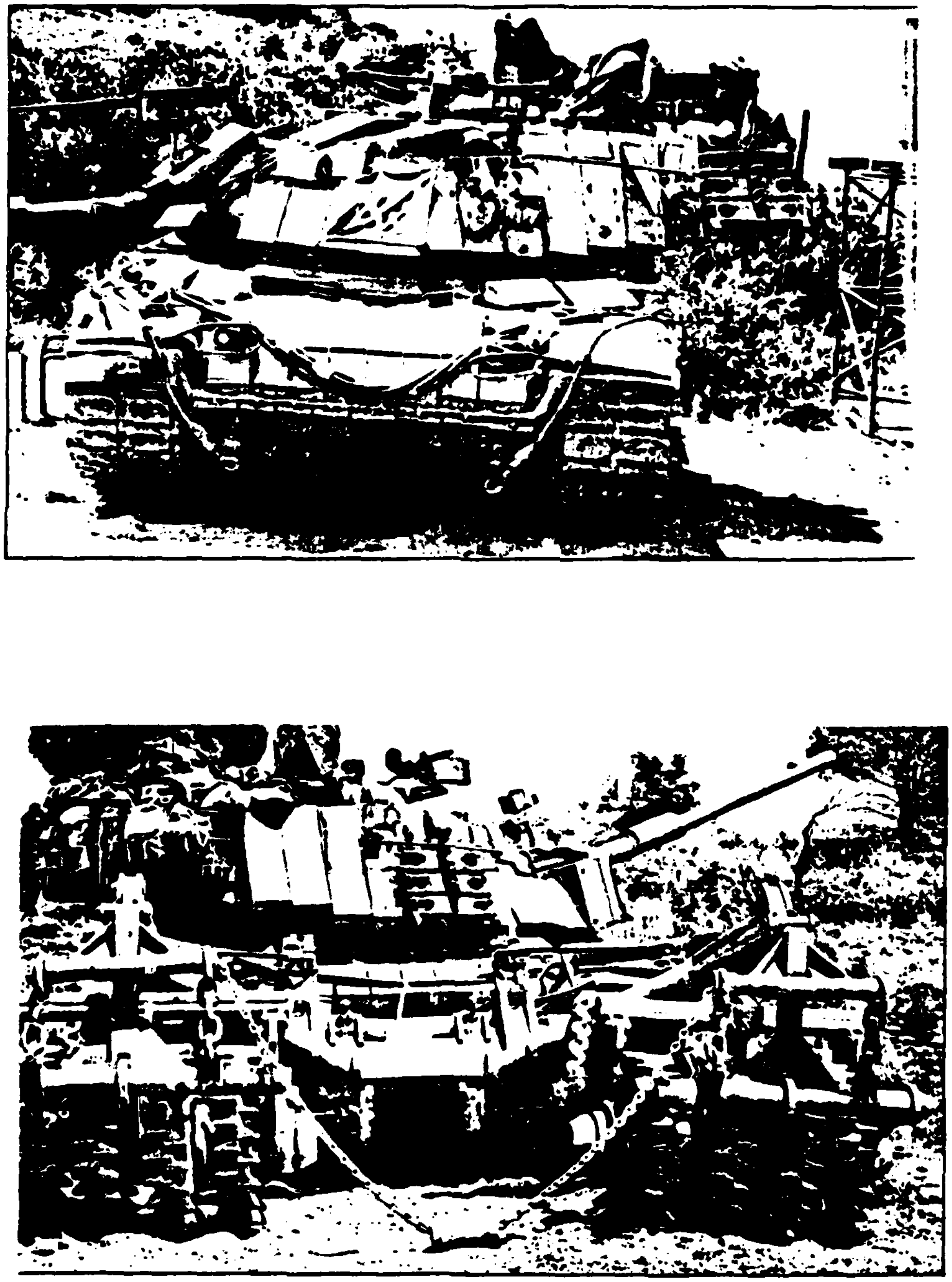


Figure 2.5. Add on Armor Blocks in M60.

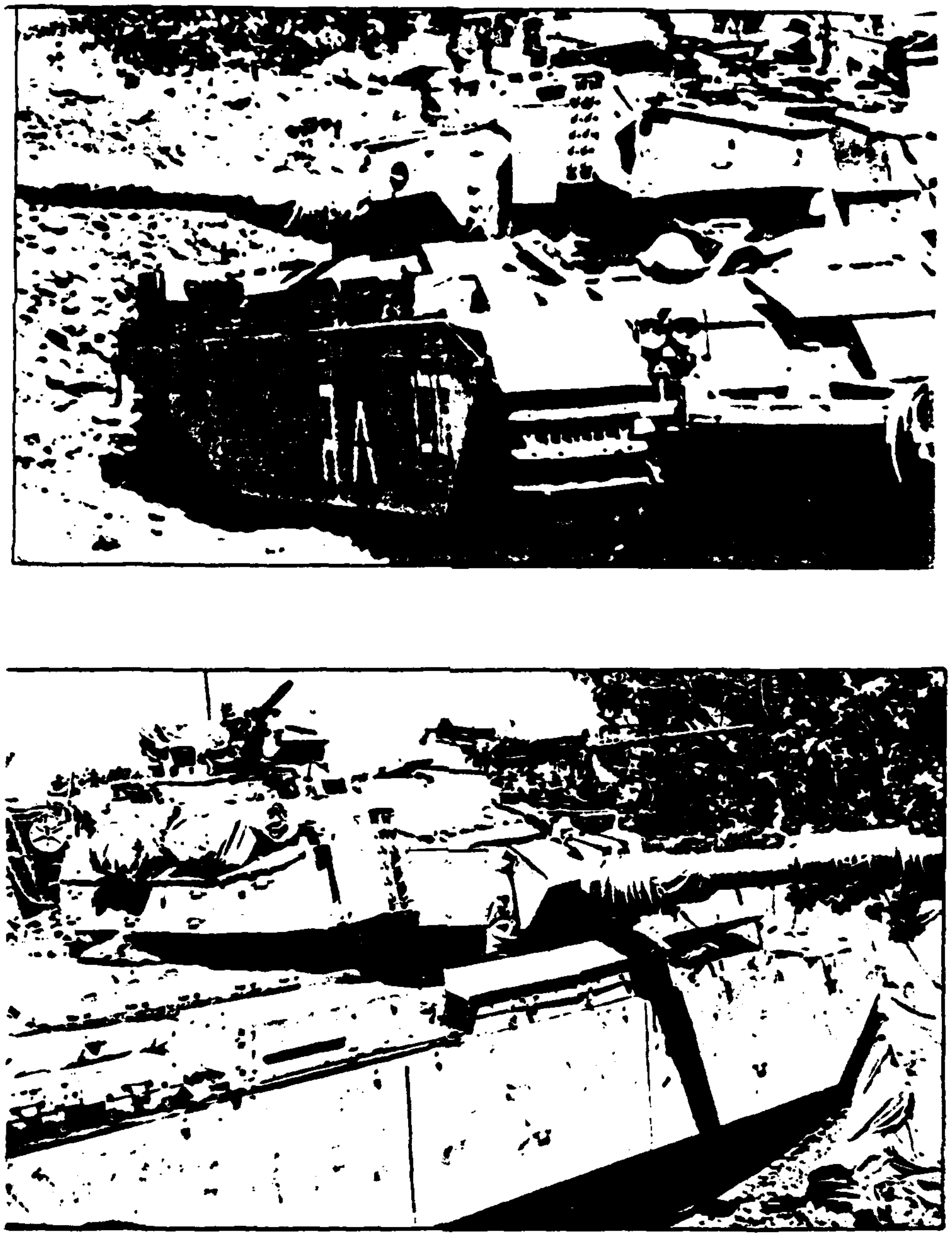


Figure 2.6. Add on Armor Blocks in Centurion.

The M60, partly because it lacks whatever protective values come with the Centurion's storage bins, has been provided with a considerable amount of add-on armor around

the turret. Here the packs are thick and vertically deep, with smaller and thinner sections patched in -- with no great concern for aesthetics -- to the upper surfaces which, because of the turret's curvature and varying angles to the perpendicular, not to mention obstructions such as lifting eyes, cannot be covered by the main boxes. As with the Centurion, panels are fitted to the front of the turret roof and to the glacis; in the latter case, because the M60's basic glacis is curved, it has been necessary to fit a straightening frame to which the packs can be attached. The M60's installation is completed by the fitting of wedge-shaped or angled sections either side of the driver's hatch to help protect the vulnerable area where turret meets hull, with further angled sections each side of, and thinner plates above, the mantlet.

Although it can be stated with a fair degree of certainty that the add-on arrays are intended to help defeat shaped-charge high-explosive anti-tank (HEAT) attack, any discussion of what the packs and panels consist of must, in the absence of any word of guidance from the Israelis - who on the contrary are happily watching, if not promoting, the circulation of a number of often fanciful and frequently mutually exclusive 'solutions' to the puzzle-fall short of a definitive answer.

While one source suggested that the boxes were empty (and the large ones on the M60 do sound quite hollow when

thumped) the probability is that there is more to it than that. In view of solutions that have been adopted elsewhere, though usually in the context of new-build tanks, it seems quite likely that the Israelis have developed their own ceramic tiles and that the boxes are partially filled with them. The alternative of a form of active armor is suggested more by the vehemence with which several sources in Israel stated this to be the case than by any objective evidence.

A number of different types and configurations of active armor are possible. An example is a sheet of explosive-laid of top of a steel plate, with a covering for environmental protection on top - which detonates when hit by the incipient jet of a shaped-charge warhead and in the process disrupts the jet's further formation. If the Israelis are indeed deploying a form of active armor, such a fact would carry the implication that they have sufficiently overcome the formidable difficulties that seem to have prevented larger and better-endowed countries from doing likewise; the United States and Soviet Union are among the nations that are known to have been engaged in related research and experimentation for many years.

C. ELEMENTARY DETONATION THEORY

1. The following assumption will be taken for the simplest analysis of a detonation: [Ref. 2]

a) The flow (motion of the shock front) is one dimensional

b) The plane detonation front is a jump discontinuity at which chemical reaction is assumed to be instantaneous.

c) The discontinuity is time-independent, so that the product composition (at least directly behind the shock front) is likewise time-independent.

u represents the particle velocity of blast wind, which is that of the products behind the shock front. Subscript x represents the initial values of the properties, y those after shock. D is the detonation speed and p is the shock wave overpressure.

From mass conservation across the front we can write

$$\rho_x D = \rho_y (D-u_p) \tag{1}$$

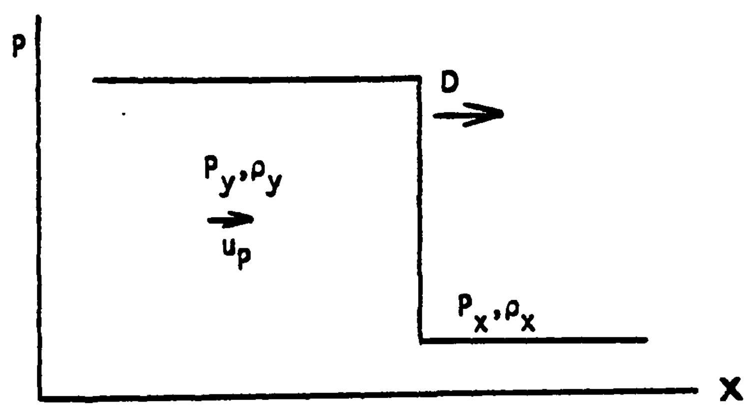


Figure 2.7. Explosive Shock Front.

and from conservation of momentum,

$$p_y - p_x = \rho_x u_p D \qquad (2)$$

Eliminating up from the two equations we obtain the equation for the Rayleigh line:

$$\rho_x{}^2 D^2 - (p_y - p_x)/(v_x - v_y) = 0 \qquad (3)$$

(Observe that in part of the previous equation we replace $1/\rho$ by the specific volume, v). Since for a detonation, $p_y > p_x$, it follows that $v_y < v_x$ (for real values of the detonation velocity); and, indeed, it is observed as a rule that there is about a one-third increase in density on detonation. If this condition is substituted in eq (1), it follows that $0 < u_p < d$, so that the products travel toward the detonation front, though trailing behind.

If the Rayleigh equation is solved for p_y we obtain

$$p_y = (p_x + \rho_x D^2) - \rho x^2 D^2 \; v_y \qquad (4)$$

wherein p_y is linear with v_y, the slope of the line being $-\rho_x{}^2 D^2$. The conservation conditions thus require that the initial and final states of a detonation must lie at the termini of the Rayleigh line.

Conservation of energy leads to

$$E(P_y, v_y, \lambda=1) + P_y v_y + 1/2(D-U_p)^2 = E(P_x, 1/x, \lambda=0) + P_x v_x + 1/2D^2 \qquad (5)$$

in which λ = the extent of chemical reaction ($\lambda = 0$ for no reaction and 1 for complete reaction). Eliminating u and D from Eq (5), suing Eqs (1) and (2) leads to the Hugoniot curve:

$$E(P_y, v_y, \lambda=1) - (P_x, v_x, \lambda=0) - 1/2\ (P_y+P_x)(V_x-v_y)=0 \qquad (6)$$

$$\Delta\ E_H = 1/2\ (P_y+P_x)(v_x-v_y) \qquad (7)$$

ΔE_H is the internal energy of the detonation products at the very high pressure and temperature of the detonation state less the internal energy of the unreacted explosive at ambient temperature and pressure. It may be written as the sum of two terms:

$$\Delta E_H = \Delta E_T + \Delta E_p \qquad (8)$$

where ΔE_T is the internal energy change for the conversion of reactants to products isothermally, and ΔE_p is that required to warm and compress the products from ambient p and T to the detonation values. ΔE_T is often symbolized as -Q in explosive literature (Q being the heat evolved in an explosion when corrected to isothermal conditions). If the products were ideal gases, then ΔE_p would be given $\int c_v dT$, and this approximation is often made, though the products at pressures of hundreds of bars, are far from being ideal gases.

2. The Hugoniot curve is that of a hyperbola in the p-v plane. For the non-reacting case ($\lambda=0$) the hyperbola passes through the initial state, p_x, v_x; but for the case we are considering here ($\lambda=1$) it does not. The conservation laws require that the final state, however, lies on the Hugoniot curve as well as on the Rayleigh line. We consider below several cases:

For a too small $D(=d_2)$ the Rayleigh line does not intersect the Hugoniot and thus no solution exists. For

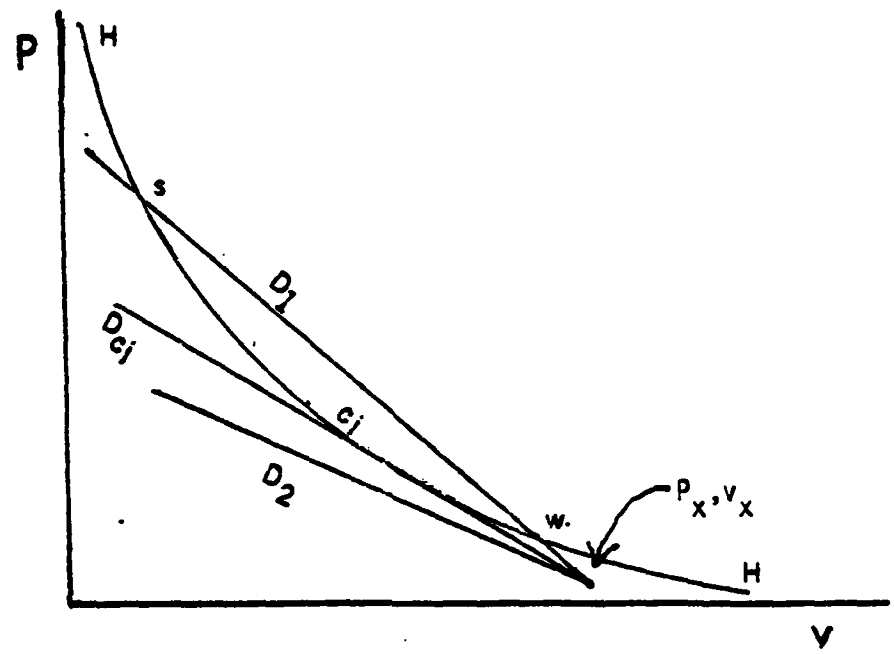


Figure 2.8. The Hugoniot Curve.

large D $(=D_1)$, there are two intersections, called strong (labelled S) and weak (W). For one particular value of D $(=D_{cj})$ the Rayleigh line is tangent to the Hugoniot.

It can be shown that the relative particle velocity, $D-u_p$, is subsonic at S $(D=u_p < a_y)$, supersonic at W and sonic at the point of tangency, called the Chapman-Jouguet point: $(D-u_p)_{cj} = a_y$ (sonic velocity in the shocked medium).

There exist a number of computer codes based on such non-ideal gas treatments (RUBY and TIGER are two of these) and moderate success has been achieved in computing detonation properties from these codes. The equations are:

$$P_y = k\rho_x^{\,2}\,\phi \tag{9}$$

$$D = A\phi^{\frac{1}{2}}\,(1 + B\rho_x) \tag{10}$$

$$\phi = NM^{\frac{1}{2}}Q^{\frac{1}{2}} \tag{11}$$

with $k = 0.762$, $A = 22.3$, $B = 0.0013$ (SI units). Q, the heat of explosion in J/kg; N, the number of moles of gas per kg; and M, the average molar mass of the gas (kg/mole are all found from an assumed stoichiometry of decomposition, combined with thermochemical principles. Although N, M, and Q are all strongly affected by the assumption made as to stoichiometry, it turns out that the important parameter, ϕ, is rather insensitive to the assumption.

III. ANALYSIS OF DYNAMIC RESPONSE OF PLATE BY SHOCK WAVES

A. THEORETICAL BACKGROUND

1. Nonlinear Static Analysis

The fundamental method used to obtain a static solution is to minimize the error vector $\{\delta\}$, given by the following equation: [Ref. 7]

$$\{\delta\} - \{P\}+ \{Q\}-\{F\} \tag{12}$$

where $\{\delta\}$ is the error vector of unbalanced forces acting at all grid points, $\{P\}$ is the vector of applied external loads, which may change with displacements, $\{Q\}$ is the unknown vector of constraint forces due to single and multipoint constraints, and $\{F\}$ is the vector of grid point forces generated by element motion and stress. The terms are functions of displacement, temperature, and stress history.

It must be noted that degrees of freedom not involved in constraints produce null terms in $\{Q\}$ and that dependent constraint points produce no errors. Therefore, when Eq (12) is reduced to the solution coordinates the constraint forces, $\{Q\}$, disappear. Terms in the vector $\{F\}$ are dependent on the deformations of the finite elements. In linear static analysis the vector $\{F\}$ becomes

$$\{F_{linear}\} = [K^{p}]\{u\} - \{p^{T}(T)\} \tag{13}$$

where $[k^P]$ = The linear stiffness matrix

$\{P^T\}$ = The "thermal load" vector, i.e., a vector of grid point which produces the same element strains as the temperature distribution,

$\{u\}$ = The vector of grid point displacements.

To obtain a nonlinear solution, a "tangent" matrix [K] is used in which the terms are derivatives in the form

$$K_{ij} = [\frac{\delta F_i}{\delta U_j}]u = u_r \qquad (14)$$

The matrix [K] contains both geometric and material nonlinear effects. The approximation occurs because the forces are highly variable with displacements and nonsymmetric terms are approximated. If $\{u^i\}$ is a known displacement which produces an error $\{\delta(u^i)\}$, then Newton's method may be used to predict a new vector $\{u^{i+1}\}$ with a smaller error. For a displacement $\{u\}$ near a known solution, $\{u^i\}$, the nonlinear force is approximately

$$\{F(u)\} \sim \{F(u^i)\} + [K]\{u-u^i\} \qquad (15)$$

The substitution of Eqn (15) into Eqn (12) with $\{\delta\} = 0$ yields the result

$$[K]\{u-u^i\} \sim \{P\} + \{Q\} - \{F(u^i)\} \qquad (16)$$

which can be written in terms of the error $\{\delta\}$ to provide the format of the Newton-Raphson iteration method:

$$[K]\{u^{i+1}-u^i\} = \{\delta(u^i)\} \qquad (17)$$

When $[K]$ may be inverted, Eqn (17) may be used to solve for $\{u^{i+1}\} = \{(u)\}$, a new estimate of the solution. Equation (17) provides an incremental form for solution iteration. Another form of the iteration equation is obtained from Eqns (12) and (17):

$$[K]\{u^{i+1}-u^{i}\} = \{p_o + p^T\} + \{Q\} - \{f^i\} - [K]\ \{u^i\} \qquad (18)$$

where

$$\{f^i\} = \{F(u^i)\} - [K]\ \{u^i\} + \{p^T\} - \Delta p(u^i) \qquad (19)$$

$[K^i]$ is the nonlinear "reference" matrix, available from the elements and $\Delta p(u^i)$ is the change in loads due to grid point motions. The advantage to this form is that the second order "corrective" load vector $\{f^i\}$ equals zero when the forces $\{F\}$ are linear and when $[K]$ contains linear elastic terms (see Eqn 13). Because the $\{f\}$ forces are calculated at the element level, all known linear elements and super-elements may be bypassed in their calculation. This is very efficient when a major portion of the structure remains linear. However, the advantages for using Eqn (17) are that the load error and incremental displacements $\{u^{i+1} - u^i\}$ are directly available for testing convergence. Therefore, in MSC/NASTRAN, both Eqns (16) and (17) are used internally.

In order to avoid calculating the vector $\{F(u^i)\}$, Eqn (19) is solved for $\{F(u^i)\}$ and substituted into Eqn (12) to obtain

$$\{\delta^i\} = \{\delta(u^i)\} = \{p + p^T\} - \{f^i\} - [K^r]\ \{u^i\} \qquad (20)$$

Subtracting $\{\delta^i\}$ for two successive values of i in Eqn (20) to eliminate the constants a simple equation is obtained for the load error in the form

$$\{\delta^i\} = \{\delta^{i-1}\} - \{f^i - f^{i-1}\} - [k]\,\{u^i - u^{i-1}\} \quad (21)$$

This form provides a simple iteration procedure, namely

a) For the first iteration after a change in the load vector, use Eqn (17) and (20). Note that the initial values for starting from rest are $\{f^o\} = \{u^o\} = 0$: calculate

$$\{\delta^o\} = \{p\} + \{p^T\} \text{ and solve } [K]\,\{u^1\} = \{\delta^o\} \quad (22)\ (23)$$

b) then compute f^1 directly from the element and load tables:

$$\{f^1\} = F\{u^1\} - [K^r]\,\{u^1\} + \{p^T\} - \{\Delta p(u^1)\} \quad (24)$$

c) then compute $\{\delta^1\}$ from Eqn (21).

$$\{\delta^1\} = \delta^o - \{f^1\} + \{f^o\} - [K^r]\,\{u^1 - u^o\} \quad (25)$$

where $\{f^o\} = 0$ by assumption.

d) Use Eqn (17) with i=1 again to compute $\{u^2\}$

$$[K]\{u^2 - u^1\} = \delta\{u^1\} \quad (26)$$

e) Repeat steps b, c and d to convergence, incrementing the superscripts by one at each iteration loop.

2. Nonlinear Transient Analysis Using MSC/NASTRAN

SOL 99 which is a rigid format of MSC/NASTRAN code for nonlinear transient problem, is the dynamic comparison to nonlinear static systems, providing for combined material and geometric nonlinear analysis in the time domain. SOL 66 which is a rigid format for nonlinear static problem and SOL 99 share the same element computer code and solution techniques

and provide similar data storage and restart facilities. The transient solution is performed in a stepwise manner with time steps replacing load steps and with effects of mass, damping and unsymmetric matrices added to the stiffness matrices.

Because the calculations are identical, many element and material discussions in the previous sections also apply to the transient analysis system. The finite elements automatically provide linear inertial forces and structural damping, based upon the initial state, as well as nonlinear forces due to geometry and material effects.

We will develop the basic equations for the transient solution. The methods were chosen to be compatible with existing MSC/NASTRAN static nonlinear solutions as well as with the existing linear transient methods. Thus, the Newmark Beta method for transient integration is combined with the modifications to Newton's method for nonlinear solutions. The additional iteration steps provide equilibrium solutions at each time step, thereby guaranteeing stability and accuracy for arbitrary time step size. The basic equations are developed below, followed by a discussion of the stability limits.

a. Basic Equation

Adding dynamic loads to the basic equation given previously, we obtain a load equilibrium error vector $\{\delta_n\}$ at time step n by equation:

$$\{\delta_n\} = \{\bar{P}_n - M\ddot{u}_n - B\dot{u}_n - \bar{F}_n$$

where $\{\bar{P}_n\}$= "Average" load over the time period

$(t_{n-1} < t_n < t_{n+1})$

$\{\ddot{U}_n\}$ $\{\dot{U}_n\}$= Corresponding acceleration and velocity vectors.

$\{\bar{F}_n\}$= "Average" elasto-plastic element total force vector.

The above equation is solved at the "reduced" (u_d) displacement vector size. The approximation errors due to dynamic reduction methods are not included in the error vector $\{\delta_n\}$. Applying Newmark's averaging method over a finite time period, $t_{n=1} < t < t_{n+1}$ the "static" forces are

$$\{\bar{F}_n\} = \{\beta F(u_{n+1}) + (1-2\beta)F(u_n) + \beta F(u_{n-1})\} \qquad (28)$$

where β = Newmark Beta operator and $F(u_n)$ is the nonlinear force due to a generalized displacement vector $\{U_n\}$. An identical definition occurs for $\{\bar{p}_n\}$ from the applied loads at each time step.

From central finite differences, the acceleration and velocity vectors are:

$$\{\ddot{u}_n\} = \frac{1}{\Delta t^2}\{\Delta u_{n+1} - \Delta u_n\} = \frac{1}{\Delta t^2}\{d_n\} \qquad (29)$$

$$\{\dot{u}_n\} = \frac{1}{2\Delta t}\{\Delta u_{n+1} + \Delta u_n\} \qquad (30)$$

where $\{\Delta u_{n+1} = \{u_{n+1} - u_n\}$

for small angles and $\Delta t = t_{n+1} - t_n$ is the "time step size". For large angle changes we require that $\{\ddot{u}\}$, $\{\dot{u}\}$, and $\{\Delta u\}$ are vectors in the global coordinate direction. The vector $\{u\}$

contains gimbal angles requiring a tranformation $R(u_n)$ such that

$$\{u_{n+1}\} = \{u_n\} + \{R_n\} \{\Delta u_{n+1}\} \tag{31}$$

the load error in terms of the current vectors estimates:

$$\{\delta_n\} = \{\overline{P}_n\} - [\frac{1}{\Delta t^2} M + \frac{1}{2\Delta t} B] \{d_n\} - [\frac{1}{\Delta t} B]\{\Delta u_n\}$$

$$- \{\beta f_{n+1} + (1-2\beta) F_n + \beta F_{n-1}\} \tag{32}$$

and

$$\{\Delta u_{n+1}\} = \{\Delta u_n + d_n\} \tag{33}$$

At any time step the vectors $\{\overline{P}_n\}$, $\{\Delta U_n\}$, $\{F_n\}$, and $\{F_{n-1}\}$ are known. In general the vectors $\{d_n\}$, $\{u_{n+1}\}$ and $f_{n+1} = F(u_{n+1})$ must be found either by approximating $\{F_{n+1}\}$ or by an iterative search.

Note that for a linear solution $\{F_n\}$ equals $[K]\{u_n\}$, where $[K]$ is the reduced stiffness matrix. In this case Eqns (32) and (33) may be used to solve for $\{u_{n+1}\}$ directly by setting $\{\delta_n\} = 0$. With $\beta=1/3$ this will produce the linear SOL 27 MSC/NASTRAN results.

<u>Nonlinear Iterations</u>

For a nonlinear solution, Equns (32) and (33) may be solved with Newton's method (or a modified version). Using $\{d_n\}$ as the primary solution variable provides the following iteration algorithm.

First assume a linear approximation:

$$\{\delta_n^{i+1}\} - \{\delta_n\} \left|\frac{\partial \delta_n}{\partial d_n}\right| \{d_n^{i+1} - d_n^{i}\} = 0 \qquad (34)$$

L-t

$$\{A_1\} = \left|\frac{\partial \delta_n}{\partial d_n}\right| \qquad (35)$$

Then, the estimated displacement change is

$$\{d_n^{i+1} - d_n^{i}\} = \{A_1\}^{-1}\{\delta_n(d_n^{i})\} \qquad (36)$$

The algorithm is identical to the static case except that instead of a tangent stiffness matrix, the "left hand side" matrix, obtained from Eqns (32) and (34) is

$$\{A_1\} = [\frac{1}{\Delta t^2} M + \frac{1}{2\Delta t} B + \beta\tilde{K}\} \qquad (37)$$

where $[\tilde{K}] = \frac{\partial F}{\partial u}$ is the current tangent stiffness matrix.

At a new time step the load iterations may be started by assuming that $\{\Delta U^{\circ}_{n+1}\} = \{\Delta U_n\}$ and therefore:

$$\{\delta^{\circ}_n\} = \{0\} \qquad (38)$$

However, to be consistent with displacements, we must extrapolate the nonlinear forces:

$$\{F^{o}_{n+1}\} \cong \{F_n + (F_n - F_{n-1})\} = \{2F_n - F_{n-1}\} \qquad (39)$$

Substituting Eqns (38) and (39) into Eqn (32) for i=0 results in the first estimate:

$$\{\delta^{o}_n\} = \{\overline{P}_n\} + [A_2]\ \{\Delta u_n\} - \{F_n\} \qquad (40)$$

where

$$[A_2] = [-\frac{1}{\Delta t} B] \tag{41}$$

Here A is a precalculated matrix. $\{\Delta U_n\}$ and $\{F_n\}$ are previous results. For subsequent iterations, (i>0) Eqn (32) becomes:

$$\{\delta_n^i\} = \{\delta_n^o\} - [A_3]\{d_{n+1}^i\} - \beta\{F_{n+1}^i - F_{n+1}^o\} \tag{42}$$

where

$$[A_3] = [\frac{1}{\Delta t^2} M + \frac{1}{2\Delta t} B] \tag{43}$$

At each time step the code will iterate on Eqns (36) and (42) until $\{\delta_n^i\}$ passes the convergence tests or the number of passes reaches an iteration limit. With a single step, i=1, calculating only δ_i, the results will be identical to the existing NOLIN results in MSC/NASTRAN. For faster convergence the iterations may continue, the matrices may be updated, and/or the time step size may be reduced.

3. Factors Determining Response to Transient Loading

The response of a metal to dynamic loading depends upon three elements which are characteristic of the material: the dynamic constitutive relation, the pressure-temperature phase diagram, and the dynamic fracture criteria. In the absence of phase changes or fracture, the material response is governed completely by the constitutive relation, or dynamic equation of state. The constitutive relation is characterized as "elastic", "viscoelastic", "visco-elastic-plastic", etc. It depends on macroscopic parameters such as

Young's modulus and the viscosity coefficient which, on a microscopic scale, arise from atomic interactions and dislocation processes. The phase diagram determines whether a given loading history will bring the metal into a pressure-temperature regime where phase transitions are possible. If this occurs during shock loading, multiple shock waves may result. Microcracks and/or voids begin to appear in a metal under tension whenever the criteria for nucleation and growth of damage are met. These criteria are functions of material parameters and the stress history.

In this chapter the dynamic constitutive relations are discussed. It is the most important element to determine the response of a metal to dynamic loadings.

In macroscopic or rheological language, iron can be described as a viscoelastic-plastic material, i.e., it responds elastically until yielding (with upper and lower yield points), and is strongly rate-dependent.

The constitutive relation, or dynamic equation of state, thus gives the stress as a function of strain and time, or, alternatively, can be written as a differential equation in $\sigma, \varepsilon, \dot{\sigma}, \dot{\varepsilon}$ and an important goal of present day research is to develop the capability to derive this macroscopic constitutive relation by averaging the effects of microscopic processes.

This is analogous to the way in which the thermodynamic equation of state of a gas is derived by averaging

the effects of the molecular collisions. Once developed, this capability would be an extremely powerful tool, since the response of a metal to dynamic loads could be predicted from known microscopic material properties. Although this goal has not been attained as yet, there has been significant progress during the last few years in this direction for the case of crystalline materials, in which dislocation processes play the role of the "molecular collisions". In iron, the density of mobile dislocations is of the order of $10^8/cm^2$, so the number of dislocations present is certainly large enough to make a statistical approach valid.

The basic approach is based on the relation from dislocation theory: [Ref. 3]

$$\dot{\gamma}^P = N_m b\nu \tag{44}$$

where $\dot{\gamma}$ is the plastic shear strain rate ($\gamma_{ij} = \frac{1}{2} (\frac{\partial \zeta_i}{\partial x_j} + \frac{\partial \zeta_j}{\partial x_i})$, where ζ_i is the displacement in the x_i direction), N_m is the mobile disclocation density, b is the Burgers vector, and ν is the average disclocation velocity. This equation provides the link between microscopic dislocation motion and macroscopic plastic straint rate, and is based on the fact that it has been found possible for many crystalline solids to express N_m and ν as functions of γ^P and applied macrosopic shear stress, τ.

The constitutive relation is obtained by combining Eqn (44) with the incremental Hooke's law

$$d\sigma_{ij} = 2\mu d\varepsilon^{e}_{ij} + \lambda d\varepsilon^{e}_{kk}\,\delta_{ij} \tag{45}$$

under the assumption that the total strain is the sum of elastic and plastic components:

$$\varepsilon_{ij} = \varepsilon^{e}_{ij} + \varepsilon^{P}_{ij} \tag{46}$$

where λ and μ are the Lame constants, δ_{ij} is the Kronecker delta, and a repeated index indicates summation. The plastic strain is assumed to cause no volume change, i.e.,

$$\varepsilon^{P}_{KK} = 0 \tag{47}$$

The combination of Eqns (46)-(48) yields, after taking the time derivative:

$$\dot{\sigma}_{ij} -2\,\mu\dot{\varepsilon}_{ij} - \lambda\dot{\varepsilon}_{KK}\delta_{ij} - 2\,\mu\dot{\varepsilon}^{P}_{ij} \tag{48}$$

In order to combine Eqn (48) with Eqn (44), we must first specify the loading geometry. In plate-slap tests under conditions of uniaxial strain, all total strain components except ε_x in the direction of wave propagation are zero, and $\varepsilon_{KK} = \varepsilon_x$. Then equation (48) becomes

$$\dot{\sigma}_x - (\lambda+2\mu)\,\varepsilon_x = -2\,\mu\,\dot{\varepsilon}^{P}_{x} \tag{49}$$

Also, in this case, the plane of maximum shear stress in isotropic media is inclined at 45° to the direction of shock propagation, and

$$\dot{\gamma}_P = \frac{1}{2}\,(\dot{\varepsilon}^{P}_{x} - \dot{\varepsilon}^{P}_{Y}) = \frac{3}{4}\,\dot{\varepsilon}^{P}_{x} \tag{50}$$

The dynamic constitutive relation for this loading geometry is thus obtained by combining Eqn (44), (49), and (50):

$$\dot{\sigma}_x - (\lambda + 2\mu)\dot{\varepsilon}_x = -\frac{8}{3}\mu N_m b\nu \qquad (51)$$

If, λ, μ, and the right-hand side of Eqn (51) are known as functions of macroscopic stress and strain, then the equation can, in principle, be solved for any problem involving uniaxial strain.

4. Dynamic Plastic Deformation of Plates

We consider cases of the impulsive loading of thin metal plates, a simple situation in which an exponential shock wave impinges on a clamped square plate. In this case, the plastic deformation is supposed to be brought about by bending only and combined bending and tension is not analytically considered. The pressure in the shock wave may be assumed to be given by [Ref. 4].

$$p = p_m \exp(-t/\tau)$$

where p is the peak pressure at a point at the head of the wave, t denotes time and τ is a time constant --- the time taken for the pressure to fall to p_{m}/e, which for high explosives is ~30 μsecs. We obtain simply, some of the results of Cox and Morland [Ref. 3], who theoretically investigated the dynamic deformation of plates, side length 2a, position-fixed at their periphery, when subject to a uniform constant transverse pressure p for time τ. Their detailed examination showed that two categories of load may

be distinguished; medium load when $p_s < p < 2p_s$ and high load when $2p_s < p$, where p_s denotes the pressure required just to enforce plastic collapse of the plate, statically For p we have, see Fig. 3-1.

$$4a\sqrt{2} \cdot W\sqrt{2} \cdot M_p = \frac{1}{3} \cdot 4a^2 \cdot aw \cdot P_s \qquad (52)$$

i.e. $\quad P_s = 6M_p/a^2$

For simplicity we deal only with their first case, and for the second, more complicated one, the reader is referred to the original source. For this medium range of loading two sub-divisions are required: (1) when $0<t<\tau$ and (2) when $t>\tau$. Use is made of the results obtained above for static situations using hinge lines, and we take over whatever results may be useful. As previously, the analysis pays no special attention to material rate effects. Further, it is implicit in this approach that the static and dynamic modes of deformation are identical.

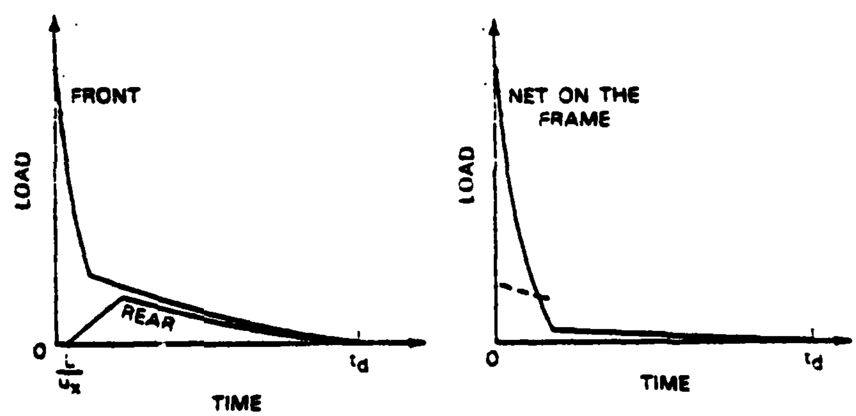


Figure 3.1. Dynamic Loading of Square Plate.

a. Medium Load: $0 < t < \tau$

Assume the mode of deformation of the plate is that of Fig. 3.2 and that the plate diagonals become hinge lines. Since p is constant and greater than p_s, and because the four equal parts of the plate act as rigid bodies each rotating about its boundary or side, they must undergo an angular acceleration, α. If changes in plate geometry throughout the deformation are neglected, the resistance to deformation, which arises from the yielding taking place in the hinge lines, will be constant; this resistance is related to p_s, the pressure to cause static yield. Thus the excess load is constant and hence α must be constant. The work done by the excess load will manifest itself as kinetic energy acquired by the four rigied regions of the plate, i.e. $4 * \frac{1}{2} I\omega^2$, where I is the moment of inertia of a triangle about a side of the plate and ω is its current angular velocity. Because α is constant, at the end of time the plate centre will have descended through a distance $vt/2$, where v is its current speed. Thus, an equation involving the work available for giving rise to rotational kinetic energy of the plate triangles is,

$$(p - p_s)\ 4a^2 \cdot \frac{vt/2}{3} = 4 \cdot \frac{1}{2} I\omega^2 \qquad (53)$$

Hence substituting for p_s from (52), noting that $I = ma^4/6$ and simplifying,

$$(p - \frac{6M_p}{a^2})t = {}^{mv}/2 \text{ or } v = 2\,\frac{(p-p_s)t}{m} \qquad (54)$$

or directly by momentum consideration, thus,

$$((p-p_s) \cdot t \cdot \frac{a \cdot 2a}{2})\frac{a}{3} = \frac{ma^4}{6} \cdot \frac{v}{a} \tag{55}$$

The deflection w_1 at the end of time τ is,

$$w_1 = v\tau/2 = (p - p_s)\tau^2/m \tag{56}$$

(2) Medium Load: $\tau > t$

After the removal of pressure p at $t = \tau$, further deflection, w_2, is added to w_1, because the rotational kinetic energy of the four plate segments must be dissipated in doing plastic work in the hinges. Let the segments rotate through further angle ϕ before coming to rest, then,

$$4 \cdot (\frac{1}{2} I \cdot \frac{v^2}{a^2}) = 4 \ a\sqrt{2} \cdot M_p \ (\phi\sqrt{2}) = 8aM_p \cdot {}^{w_2}/_a$$

Hence

$$w_2 = \frac{ma^2 v^2}{2\ 4\ M_p} = \frac{mv^2}{4p_s} = \frac{(p-p_s)^2\tau^2}{m\ p_s} \tag{57}$$

using Eqn (55). Thus the total central deflection is,

$$w = w_1 + w_2 = p\ (p - p_s)\tau^2/mp_s \tag{58}$$

If the total response time of the plate is τ_t, note that $\tau_t p_s = p\tau$. In the case of thin plates clamped at their outer periphery it is clear that after a significant amount of deflection there must be stretching. An analysis of the dishing of peripherally clamped metal plates when given a transverse initial speed of a few hundred feet per second has been given by Hudson [Ref. 3]. Descriptively, Hudson's

model is easily understood by reference to Fig. 3-2. Central portions of the plate maintain their given transverse speed until overtaken by a bending wave propagated radially inwards from the clamping ring. Fig. 3-2(a) shows the imagined plate configuration at successive intervals during the deformation process; when the plate deflection is significant, the process is predominantly one of stretching and for many practical purposes the technological approach is adequate.

Figure 3-2(a) shows the terminal state taken up by a thin rectangular steel plate clamped around its periphery after being subjected to the uniform but intense impulsive loading, the maximum speed of the plate is a few hundred feet per second, but contracting in area with time; the dynamic situation during deformation, with plastic hinges moving into the plate from the clamped edges and intersecting along lines equally inclined to the sides from the corners, is indicated diagrammatically in Fig. 3-2(b).

Now the yield criteria of metals should be considered. Two approaches to the interpretation of a yield criterion are possible; one is Tresca's criterion, the other is Von Mises criterion. But for most metals it is generally found that while the experimental points fall between the two ellipses, they incline towards Von Mises' ellipse. Experiments were earlier performed by Lode (1925) on tubes subject to tension and internal pressure. Bending and torsion was used by Siebel in 1953. All results confirm the general opinion that the best simple yield criterion for metals is that of Von Mises [Ref. 5].

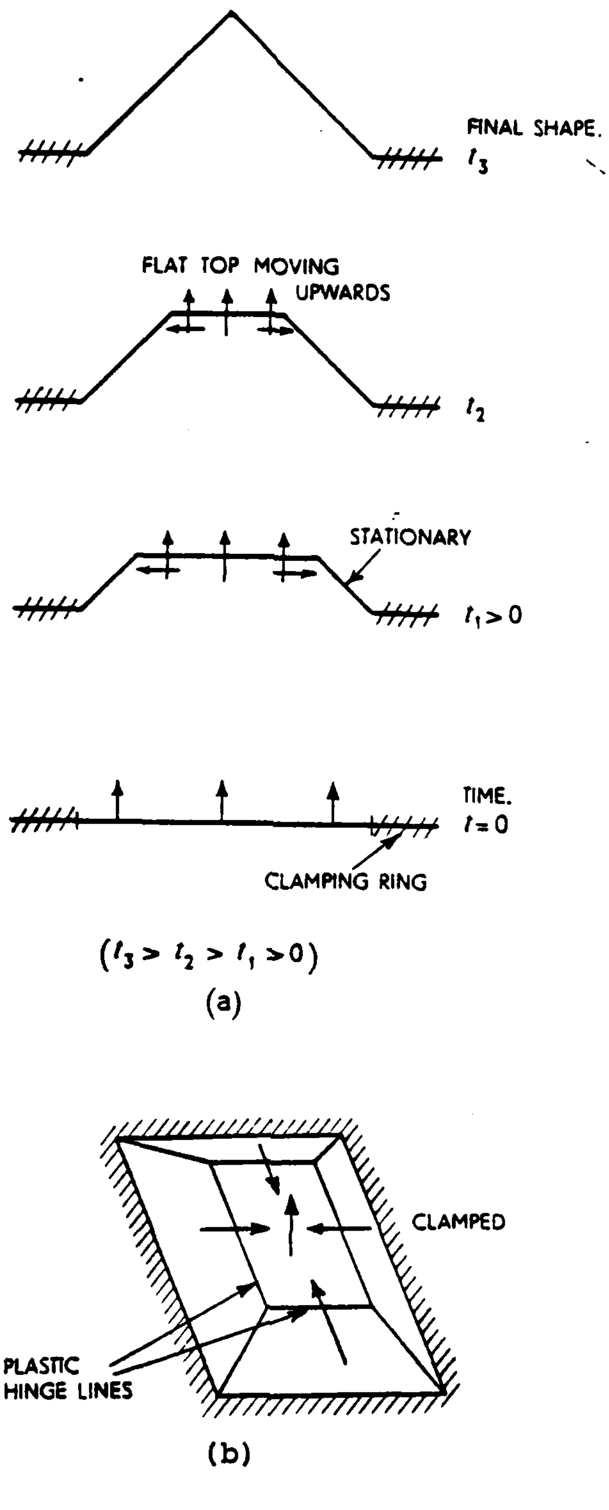


Figure 3.2. Dynamic Deformation of Fixed Square Plate.

B. PROBLEM DESCRIPTION AND NASTRAN DECK SETUP

1. Problem Description

The model is shown in Fig. 3.3. It is a 20 in. by 20 in. steel square plate model which is divided to 25 QUAD4 (NASTRAN card) elements and its boundary is clamped. Its thickness is 0.8 inches and the engineering data as follows.

$E = 3.0E+7$

$\nu = 0.3$

$L = 20.0$ in.

$\rho = 7.33E-4$ lb/in^3

$t = 0.8$ in.

where E is the elastic modulus, ν is the Poisson's ratio, L is the length of the plate, ρ is the mass density, and t is a thickness of the plate.

Next the shock wave applied impinges on the steel plate in the -Z direction at time 0.0 seconds (Fig. 3.4) and its peak overpressure is 3.0E+4 psi and the shock wave duration time (t_d) is 5.0E-3 secs. To find the pressure, the following formula is used [Ref. 6]

$$p = p_m(1-t/t_d) \exp(-\alpha t/t_d)$$

where p_m is peak reflected overpressure at time 0.0 secs and α is wave form parameter. But the shock wave pressure cannot be applied as a load to the plate since the front face shock pressure of the plate is relieved by the rear face shock wave which is positive Z direction. The following formula is used [Ref. 4].

$$p = p_m \exp(-t/\tau)$$

The load data as follows.

peak lateral loads (-Z direction)

p = 3.E+4 psi on the Element (213)

p = 2.2E+4 psi on the Element (207, 208, 209, 212, 214, 217, 218, 219)

Von Mises criterion would be applied for this model. The time step (t) to be applied is 1.0E-6 secs from 0.0 sec to 7.0E-4 secs.

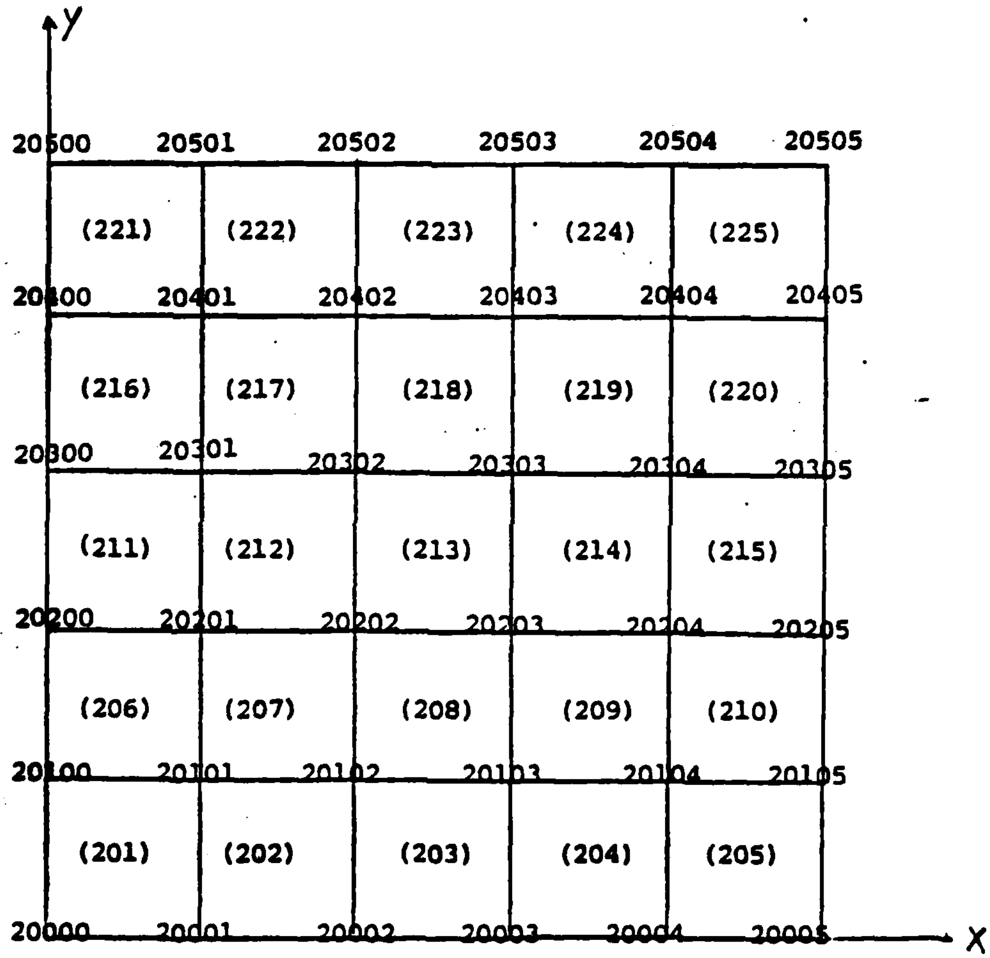


Figure 3.3. Modeled Steel Square Plate.

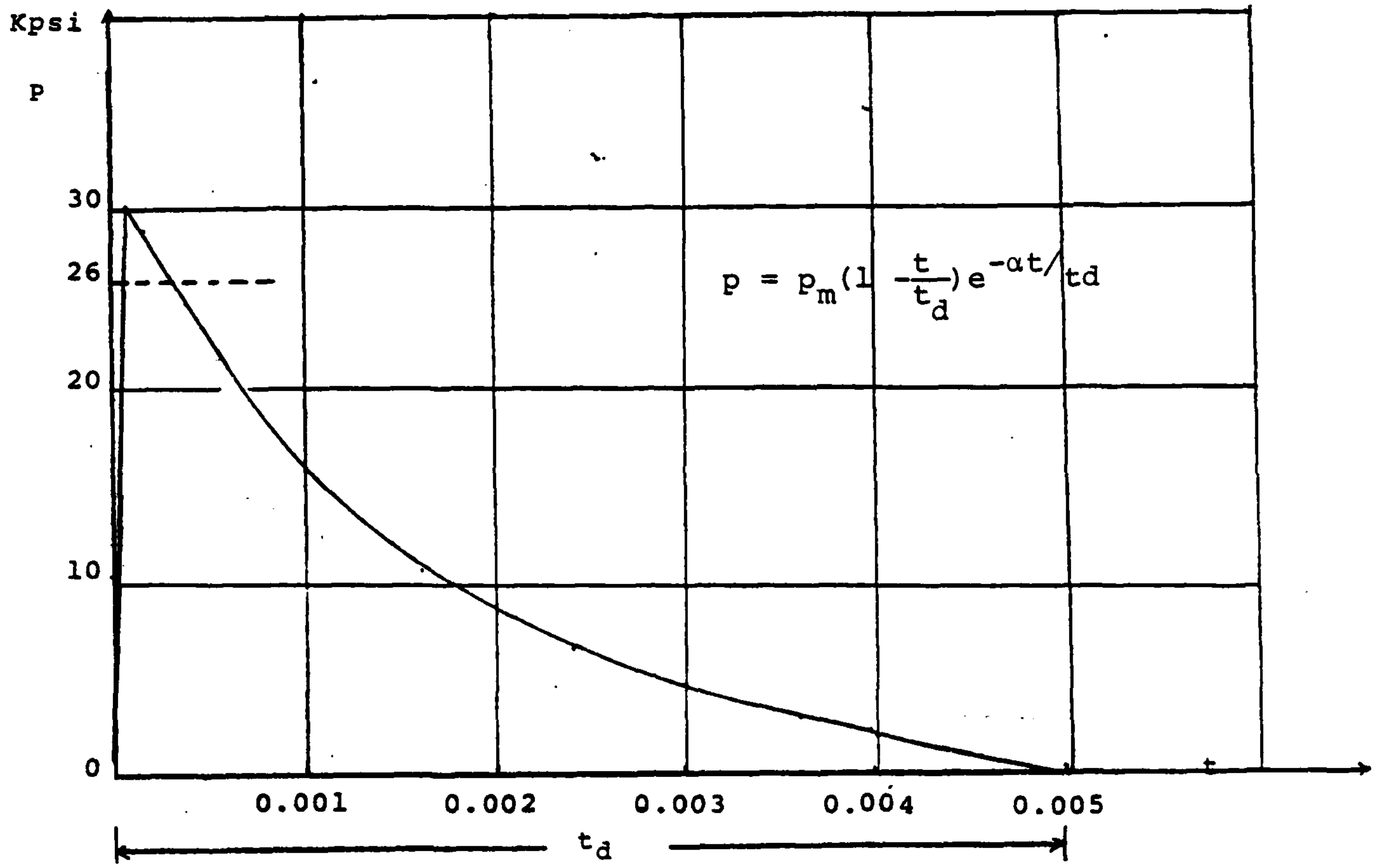


Figure 3.4 Shock Wave Applied.

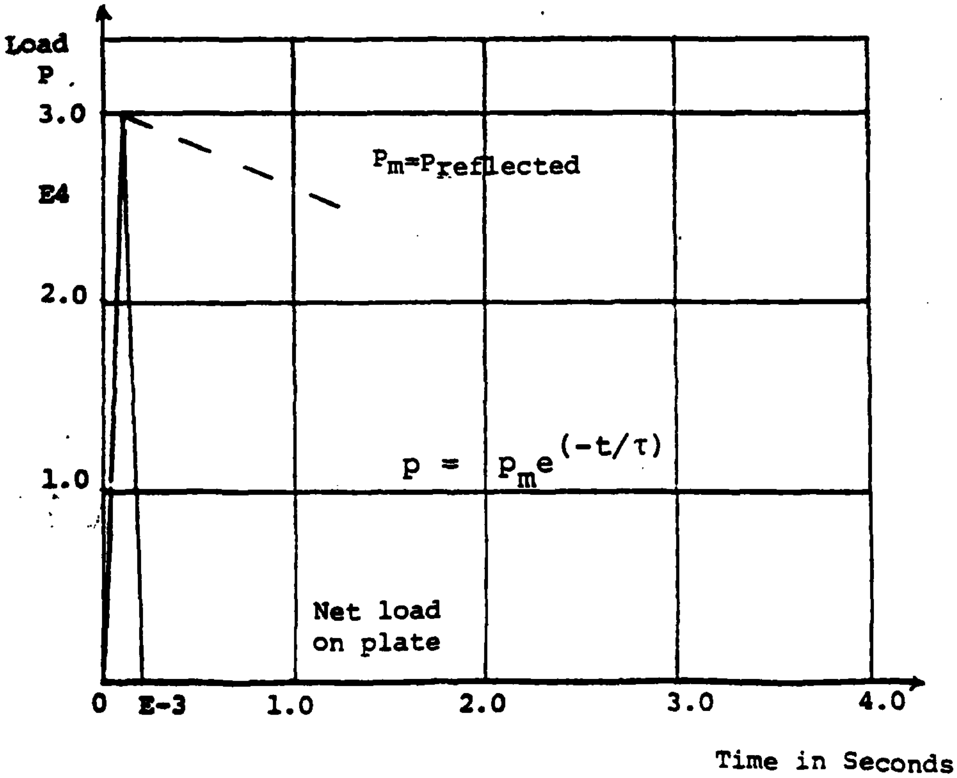


Figure 3.5. Loading History.

2. NASTRAN Input Data Deck

Reference is made to the echo of the input data deck which appears in the output.

a. Sol 66 [Ref. 6]

```
NASTRAN PREFOPT=2
ID NONLINEAR, STATIC
SOL 66
TIME 30
CEND
TITLE-NONLINEAR DEFORMATION WITH STATIC LOADS
SUBTITLE=TRANSIENT RESPONSE BY SHOCK WAVE LOAD.
ECHO=UNSORT
DISP=ALL
OLOAD=ALL
SPCF=ALL
GPFOR=ALL
ELST=ALL
SEALL=ALL
SPC=200
SUBCASE 1
LOAD=10
NLPARM=10
BEGIN BULK
$
$ LATERALLY LOADED FLAT PLATE
$
```

```
MESHOPT,,,,,YES
$
$ USE MSGMESH TO GENERATE 5*5 ARRAY OF QUAD4 ELEMENTS
$
EGRID,1,,0.,0.
EGRID,2,,20.,0.
EGRID,3,,20.,20.
EGRID,4,,0.,20.
GRIDG,2,,,5,-1,-2,-3,,+FLD2
+FLD2,5,-4
CGEN,QUAD4,201,200,2
$ REFER TO PAGE 2.18-7,APPLICATION MANUAL.
PSHELL,200,65,0.8, 65,,65
MAT1,65,3.0E+7,,.3,7.33E-4
MATS1,65,40,PLASTIC,,1,1,2.6E+4
TABLES 1,40,0,,,,,,,+TAB1
+TAB1,0.0,0.0,0.001,3.0E+4,0.025,4.-E+4,0.05,5.8E+4,+TAB2
+TAB2,0.10,6.7E+4,0.125,7.0E+4,0.2,7.5E+4,FNDT
PARAM,COUPMASS,1
PARAM,K6ROT,1.0
PARAM,LGDISP,1
PLOAD2,10,-14.7,208,212,213,214,218
NLPARM,10,1,,AUTO,,20,W,YES
$NLPARM,20,3,,AUTO,,20,W,YES
SPCG,200,2,123456,A,B
SPCG,200,2,123456,B,C
```

```
50    SPCG,200,2,123456,C,D
51    SPCG,200,2,123456,A,D
52    ENDDATA
```

1) Executive control card

card 1 - The NASTRAN card contains the keyword PREFOPT = 2 which requests that MSGMESH be used to generate input data.

card 3 - Request nonlinear static analysis, Rigid format 66.

2) Case control card

card 15 - Requests superelement generation and assembly

* should be set as 'all'

card 18 - Requests static load combination.

* SID should be matched to the PLOAD2 card in the bulk data deck.

card 19 - Requests nonlinear parameter selection.

* SID should be matched to the NLPARM card in the bulk data deck.

* This card may appear above or within a subcase.

* LOAD card is only applicable in statics, buckling, heat transfer problems.

3) Bulk data cards

card 24 - Requests out options control

* An entry of YES causes the printing of the 'input card echo'.

card 28-31 - Defines vertices of quadrilateral field using MSGMESH EGRID command.

card 33 - Defines a field of grid points and generate grid cards.

* The grid number generated by MSGMESH starts from the FID of GRIDG (if FID is 2, the first grid point ID is 20000)

* 5 means 5 elements in each direction.

card 34 - Generate element connection.

* QUAD4 is the element type which should be generated.

* Element ID number starts from 201.

* Fifth field 200 is the PID of pshell card.

card 38 - Specifies table references and material properties which are stress-dependent for use in material nonlinearity applications

* Taken Von Mises yield function, isotropic hardening rule.

card 39 - Represent stress-strain data.

card 43 - The value 1.0 suppresses singularities

* It is intended primarily for geometric nonlinear analysis.

card 44 - The value 1 allows the nonlinear calculations.

card 45 - Request the initial condition on the elements in the negative Z direction.

card 46 - Controls the nonlinear analysis iteration.

* To reduce the output, use sixth field.

* For rapid convergence, increase the Error tolerance and maximum iteration and the limit on diverging iterations.

card 48-51 - Generate spcl cards.

This card is only used to MSGMESH generation.

b. Sol 99

```
NASTRAN PREFOPT=2
ID NONLINEAR,TRANSIENT
SOL 99
TIME 59
CEND
TITLE=NONLINEAR DEFORMATION WITH DYNAMIC LOADS
SUBTITLE=TRANSIENT RESPONSE BY SHOCK WAVE LOAD.
ECHO=SORT
SET 1=20202,20203,20204,20304,20404
SET 2=201,208,212,213,214,219,225
SET 3=20000,20003,20005,20200,20400
SDISP=1
OLOAD=1
SPCF=3
ELST=2
SEALL=ALL
SPC=200
LOADSET=77
SUBCASE 1
```

```
DLOAD=37
TSTEPNL=45
SUBCASE 2
DLOAD=37
TSTEPNL=46
SUBCASE 3
DLOAD=37
TSTEPNL=47
OUTPUT(XYPLOT)
PLOTTER NAST
CSCALE 1.3
XTITLE=TIME IN SECS
XGRID LINES=YES
YGRID LINES=YES
YTITLE=DISPLACEMENT GRID 20202
XYPLOT SDISP RESP/20202(T3)
YTITLE=VELOCITY GRID 20202
XYPLOT SVELO RESP/20202(T3)
YTITLE=DISPLACEMENT GRID 20101 20102 20202
XYPLOT SDISP RESP/20101(T3),20102(T3),20202(T3)
BEGIN BULK
$
$ LATERALLY LOADED FLAT PLATE
$
MESHOPT,,,,,YES
$
```

```
$ USE MSGMESH TO GENERATE 5*5 ARRAY OF QUAD4 ELEMENTS
$
EGRID,1,,0.,0.
EGRID,2,,20.,0.
EGRID,3,,20.,20.
EGRID,4,,0.,20.
GRIDG,2,,,5,-1,-2,-3,,+FLD2
+FLD2,5,-4
CGEN,QUAD4,201,200,2
$ REFER TO PAGE 2.18-7,APPLICATION MANUAL
PSHELL,200,65,0.8,65,,65
MAT1,65,3.0E+7,,.3,7.33E-4,,,0.01
MATS1,65,40,PLASTIC,,1,1,2.6E+4
TABLES1,40,0,,,,,,,+TAB1
+TAB1,0.0,0.0,0.001,3.0E+4,0.025,4.0E+4,0.05,5.8E+4,+TAB2
+TAB2,0.10,6.7E+4,0.125,7.0E+4,0.2,7.5E+4,ENDT
PARAM,COUPMASS,1
$PARAM,AUTOSPC,YES
PARAM,W4,1.616E+3
PARAM,K6ROT,1.0
PARAM, LGDISP,1
PARAM, SLOOPID,1
PARAM,LOOPID,1
PARAM, STIME,0.000450
PARAM,MAXLP,7
DLOAD,37,1.0,1.0,7,1.0,6,1.0,5
```

```
72   TLOAD1,7,61,,0,22
73   LSEQ,77,61,71
74   PLOAD2,71,3.2E+4,213
75   TLOAD1,6,62,,0,22
76   LSEQ,77,62,81
77   PLOAD,81,2.5E+4,207,208,209,212,214
78   TLOAD1,5,63,,0,22
79   LSEQ,77,63,91
80   PLOAD2,91,2.5E+4,217,218,219
81   TABLED1,22,,,,,,,,+NEXT1
82   +NEXT1,-1.,0.0,0.0,-0.0010,0.0001,-1.0,0.0010,-0.560,+NEXT2
83   +NEXT2,0.004,-0.001,ENDT
84   TSTEPNL,45,150,1.0E-6,20,AUTO,,20,W,+LL1
85   +LL1,1.0E-7,1.0E-7,1.0E-7,20,20,10
86   TSTEPNL,46,200,1.0E-6,20,AUTO,,20,W,+LL2
87   +LL2,1.0E-5,1.0E-5,1.0E-5,20,20,10
88   TSTEPNL,47,120,3.0E-6,20,AUTO,,20,W,+LL2
89   +LL2,1.0E-4,1.0E-4, 1.0E-4,20,20,10
90   SPCG,200,2,123456,A,B
91   SPCG,200,2,123456,B,C
92   SPCG,200,2,123456,C,D
93   SPCG,200,2,123456,A,D
94   ENDDATA
```

1) Executive control cards

card 3 : Requests nonlinear transient analysis, Rigid format 99.

2) Case control cards

card 18: Selects a static load set for use in dynamics. Thus this may be referenced by dynamic loads.

card 20: This card selects a dynamic load for nonlinear transient problem.

card 22-24: Requests restart at time 0.00015 secs.

card 25-27: Requests restart at time 0.00035 secs.

card 28-39: Requests the xy plotting which is corresponding to the time step.

3) Bulk data cards

card 64: This gives damping effects for transient analysis.

* Sometimes, more rapid convergence effects can be obtained by this damping factor with damping coefficient in MAT1 card (GE).

card 67: This card identifies the initial conditions from a previous SOL 66 nonlinear static solution.

* Refer to the param card, SLOOPID.

card 68,69: Request these two cards when we taken more than one subcase.

card 70: Requests more internal calculation.

* We can reduce iteration steps and prevents the overprinting due to iteration steps.

card 71: Defines a dynamic loading condition for transient response problems as a linear combination of load sets

* See the remarks 5, 7, 9 of DLOAD card in bulk data.

card 72, 75, 78: Defines time dependent dynamic load.

* Requests a static load card set (LESQ).

card 73, 76, 79: Defines a sequence of static load sets. This load sets may be referenced by dynamic load card (TLOAD1)

* This card should be used when we want to apply area pressure on elements than a point pressure on grid point.

card 74, 77, 80: Defines a uniform static pressure load on the plate elements.

card 81-83: Defines a tabular function for use in generating a time-dependent dynamic loads.

* In this card the peak pressure (3.0E+4 psi) occurred at 0.0001 sec.

card 84, 86, 88: This card control the nonlinear transient analysis.

* This card is expalined in the sensitivity analysis.

C. SENSITIVITY ANALYSIS

1. General

In transient analysis, two types of instability could occur. The first is the familiar nonlinear load iteration divergence which also occurs in static analysis. The second

is the divergence which grows with time in the transient integration. Both instabilities are caused by uncorrected nonlinear equilibrium errors.

A convenient method, from Von Neumann, for analyzing the stability limits is to assume that the nonlinear forces are nearly linear and the error vector has a constant convergence. It is assumed that the nonlinearity has a first order approximation: [Ref. 7]

$$\{F(\mu)\} \sim [K^r + \Delta K^{NL}] \{\mu\} \tag{59}$$

where ΔK^{NL} is the difference between the tangent stiffness matrix and its approximation K^r. The error vectors, $\{\delta\}$, are assumed to grow at the rate λ, defined as:

$$\{\delta^{i+1}\} = \lambda\{\delta_i\} \tag{60}$$

Note that if $|\lambda| > 1$ the system will be defined as unstable.

After lengthy calculations we may summarize the various criteria, assuming that the matrices are reduced to equivalent scalar modal quantities, the criterian for stable solutions are:

1) For time steps with converged "static" iterations:

$$1/2 > \beta \geq 1/4$$

This is the same criteria as linear analysis.

2) For "static load" iterations:

$$\beta \, \Delta \, K^{NL} \leq \beta \, K^r + \frac{1}{2\Delta t} B + \frac{1}{\Delta t^2} M$$

This states that the mass and damping add to the effective linear stiffness $[K^r]$ and improve the stability.

3) For time step integration with no intermediate static iterations, as in the standard Newmark Beta method:

$$\Delta K^{NL} \leq (4\beta - 1) K^{r} + \frac{4}{\Delta t^{2}} M$$

This restriction is more severe than criteria b above, proving that the internal iterations are more stable than the Newmark integration.

In summary, the Von Neumann method will have fewer divergence problems than either the static nonlinear solution or the single step transient nonlinear methods. The better stability of the method and the capability to use larger time steps outweighs the cost of a few internal iterations on the static element forces.

2. Nonlinear Transient Controls

The input data required for SOL 99 is a combination of transient control data, similar to SOL 69 (Direct Transient, superelements), and nonlinear modeling data similar to SOL 66 (Nonlinear Statics). The nonlinear properties are defined by nonlinear material data (MATS1), gap elements (GAP), and large displacement effects (parameter LGDISP). The transient effects are produced by loading functions (TLOADi, DAREA, etc.), damping (parameters, elements, and material data), and element mass properties.

The only unique data required for SOL 99 is supplied on the TSTEPNL data cards. (Several optional parameters are provided for tuning the method and for use in restarts.) The TSTEPNL card in itself is an amalgam of the normal transient TSTEP card and the nonlinear control card, NLPARM.

a. Case Control

The significant rules for nonlinear transient are:

1) Each subcase defines a time interval starting from the last time step of the previous subcase which is subdivided into small time steps. The output TIME printout will be labeled by the net time, including all previous subcases.

2) The input loading functions may be changed for each subcase or continued by repeating the same DLOAD request. The bulk functions are evaluated at the net model time, which starts at the last time step of the previous subcase.

3) Each subcase may have a different time step size, time interval, and iteration control selected by the TSTEPNL request. The case control requests which may not be changed after the first subcase are: SPC, MPC, DMIG, and TF.

4) Output requests for each subcase are processed independently and the output for each case are generated before the next subcase is processed. Separate XYPLOT ouputs will occur for each subcase. Available outputs are DISPLACEMENT, VELOCITY, ACCELERATION, OLOAD, STRESS, FORCE, SDISPLACEMENT, SVELOCITY, and, SACCELERATION. Note that NONLINEAR and SPCFORCE outputs are not provided.

5) Initial conditions are not explicitly provided for user input in SOL 99. The reason is that the nonlinear element configuration and equilibrium state must be known at every time step. If initial conditions were given, all of the nonlinear element forces and plastic stresses, as well as the past history, must be given. Therefore, the initial

conditions become part of the analysis and are generated by initial transient subcase or by restarts from a previous static solution.

6) All normal superelement model generation options and matrix reduction options are allowed for the linear portion of the structure. General Dynamic Reduction, Component Mode Synthesis, and Guyan Reduction may be performed for nonresidual superelements. Therefore, the residual superelement may contain scalar degrees of freedom representing linear model formulations.

b. TSTEPNL Data

The TSTEPNL data card description is provided in Section 2 of the MSC/NASTRAN User's Manual. The input fields specify the time step size, the number of steps, and the output interval as well as the nonlinear iteration options.

The nonlinear iteration data are provided for controlling the accuracy and stability of the nonlinear calculations and they will not effect linear solutions. The controls are similar to those on the NLPARM bulk data used in static nonlinear analysis.

As discussed above two types of errors or instability are encountered in the transient solution. The load iterations are similar to static load analysis and may diverge at one or more time steps when large nonlinear stiffness changes occur. Load iteration divergence may be cured by smaller time steps or by stiffness matrix updates. The

diagnostic output value LAMBDA-I (from DIAG 50) indicates the rate of growth of this error.

The second type of divergence occurs in the time domain when the load iterations do not converge, or are limited by the user. The errors may increase for each new time step until they cause the code to abort. This problem may be cured by allowing more load iterations or by using smaller time steps. The diagnostic output value LAMBDA-T (from DIAG 50) indicates the rate of growth of this error.

The size of the time step is of primary importance in transient analysis to control accuracy and avoid diverging solutions. The use of several subcases with different time step sizes to correspond with nonlinear activity is recommended as a normal procedure. When the user wishes to avoid overly-small time steps for highly nonlinear zones, he may increase the iteration limits and/or the error tolerance and the divergence limits.

c. Restarts and Data Base

Solutions 66 and 99 share the same data base/superelement file storage logic for the nonlinear tables and matrices. Therefore, the restart system for transient analysis is allowed to use either a previous static or transient nonlinear analysis as initial conditions.

For restarting from previous static analysis only the first subcase is affected. Simply provide a data base created in SOL 66 and specify the parameter.

PARAM,SLOPPID,N

where N was the printed value of LOOP for the desired static solution. Constraint sets, direct input matrices, mass, and damping may be changed.

Restarts from a previous transient execution are available for a number of cases. If the same model is to be reexecuted, only the residual superelement needs to be reassembled (SEMA, SELA=0). If the end results for the previous transient run are to be used for the initial conditions at t=0, add the parameter LOOPID=N where N corresponds to the Nth subcase of the previous run and N dummy SUBCASE commands to start the residual case control execution.

The normal restart for a transient run is to continue from the last step of a previous subcase with different loads and/or TSTEPNL data. Provide the following parameters:

LOOPID = N - Start from the Nth subcase

Stime = t - Start from time t.

Note that constraint sets should not be changed to avoid incompatible matrix sizes.

D. NUMERICAL RESULTS

The progressive deformations of the plate are plotted along the x-axis at five different time locations as shown in Fig. 3.6(b). At the early time (1.5E-4 secs), the response of the plate is in the elastic region. During the deformation, plastic hinge lines are formed along the clamped edges and the

diagonals of the plate as indicated in Fig. 3.6(a). This response phenomenon agrees well with Hudson's studies [Ref. 4]. As described in Section A-4 of Chapter 3, when the plate deflection is significant, the plate experiences in-plane stretching.

Time history displacement responses of Grid points 20101, 20201, and 20202 are plotted in Fig. 3.7. As shown in the figure, for the short duration impulse, the maximum displacement occurs at the center of the plate after termination of shock loading. The rate of increase in displacement is the maximum at the termination of shock loading as shown in Fig. 3.8. During the application of the shock loading, the acceleration level is high, implying the high inertia force in the system. At the termination of the inertia force in the system, the acceleration stays in the constant level until the plate displacement reaches the maximum.

Time hisotry Von-Mises stress of QUAD4 element 213 (plate center) is plotted in Fig. 3.7. The stress variation is highly non-linear due to the material non-linearity.

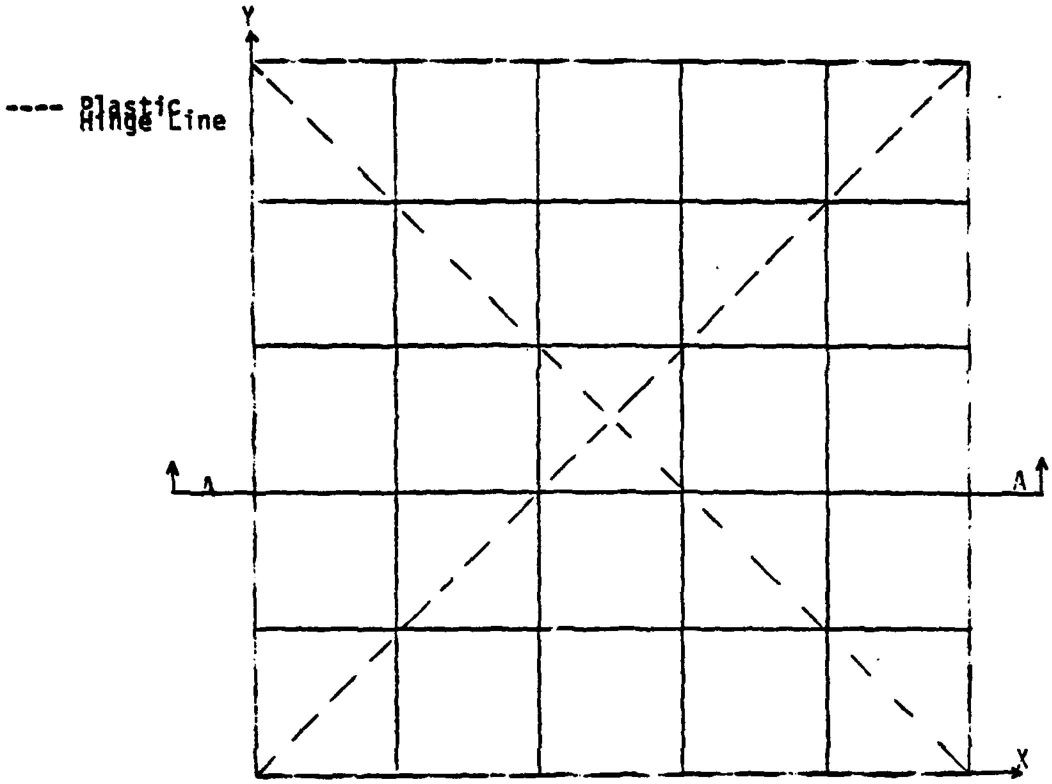


Figure 3.6(a). Plastic Hinge Line Formation.

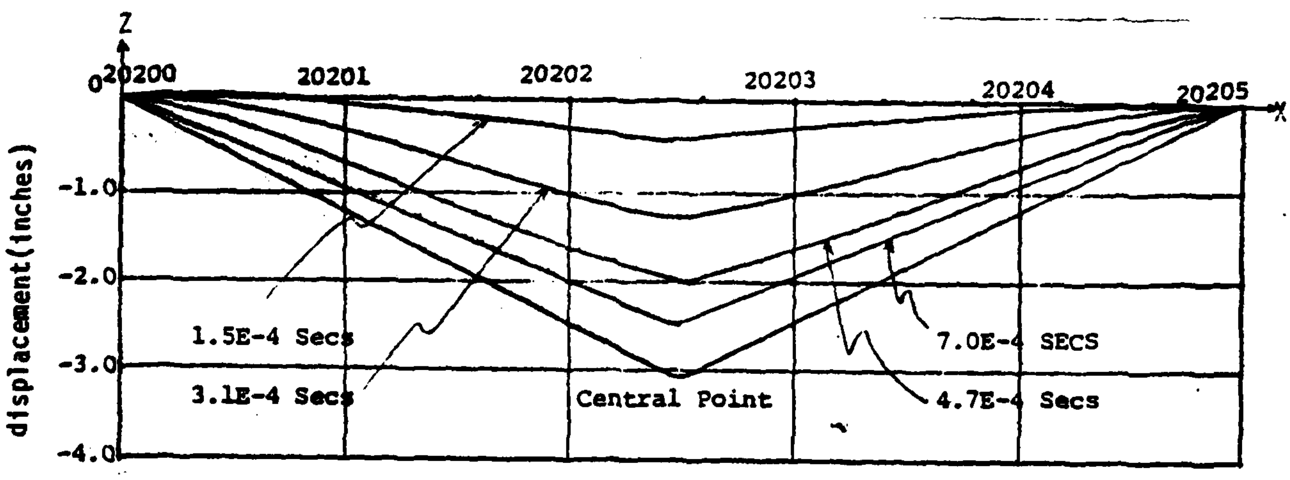


Figure 3.6(b). Progressive Deformation of the Plate Along Section A-A.

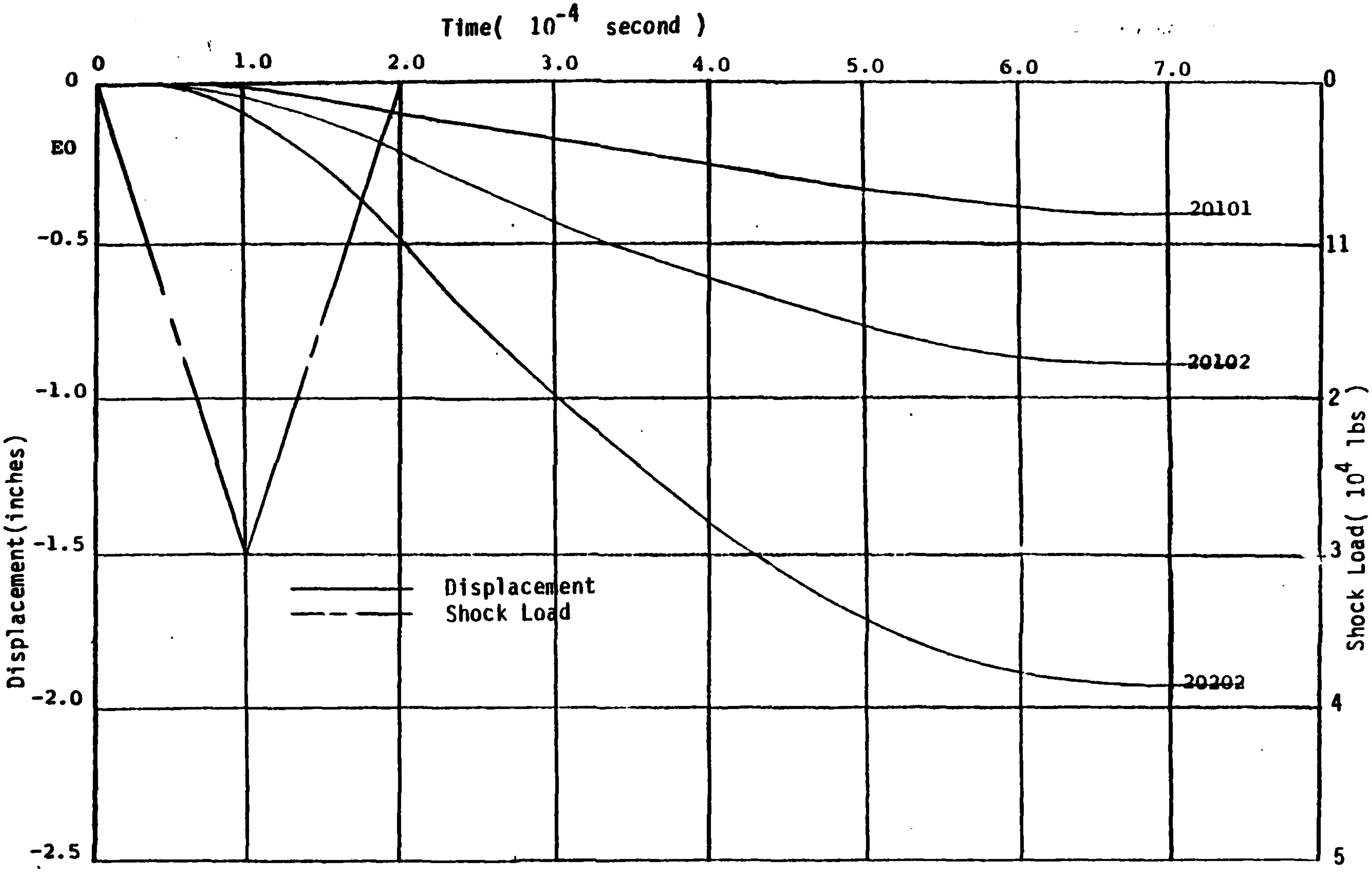


Figure 3.7. Time History Displacement Responses of Grid Points 20101, 20201, 20202.

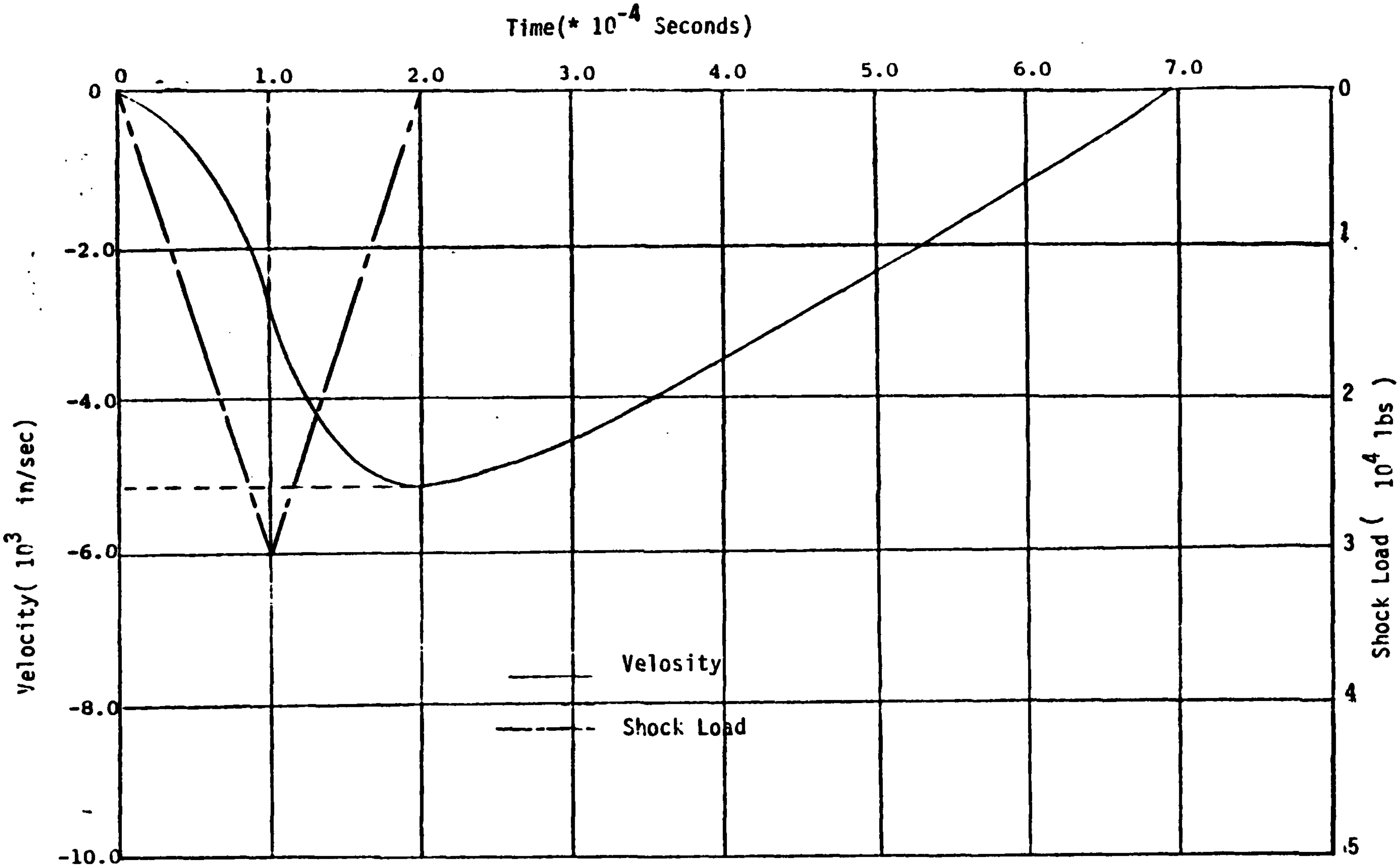


Figure 3.8. Time History Velocity Responses of Grid Point 20202.

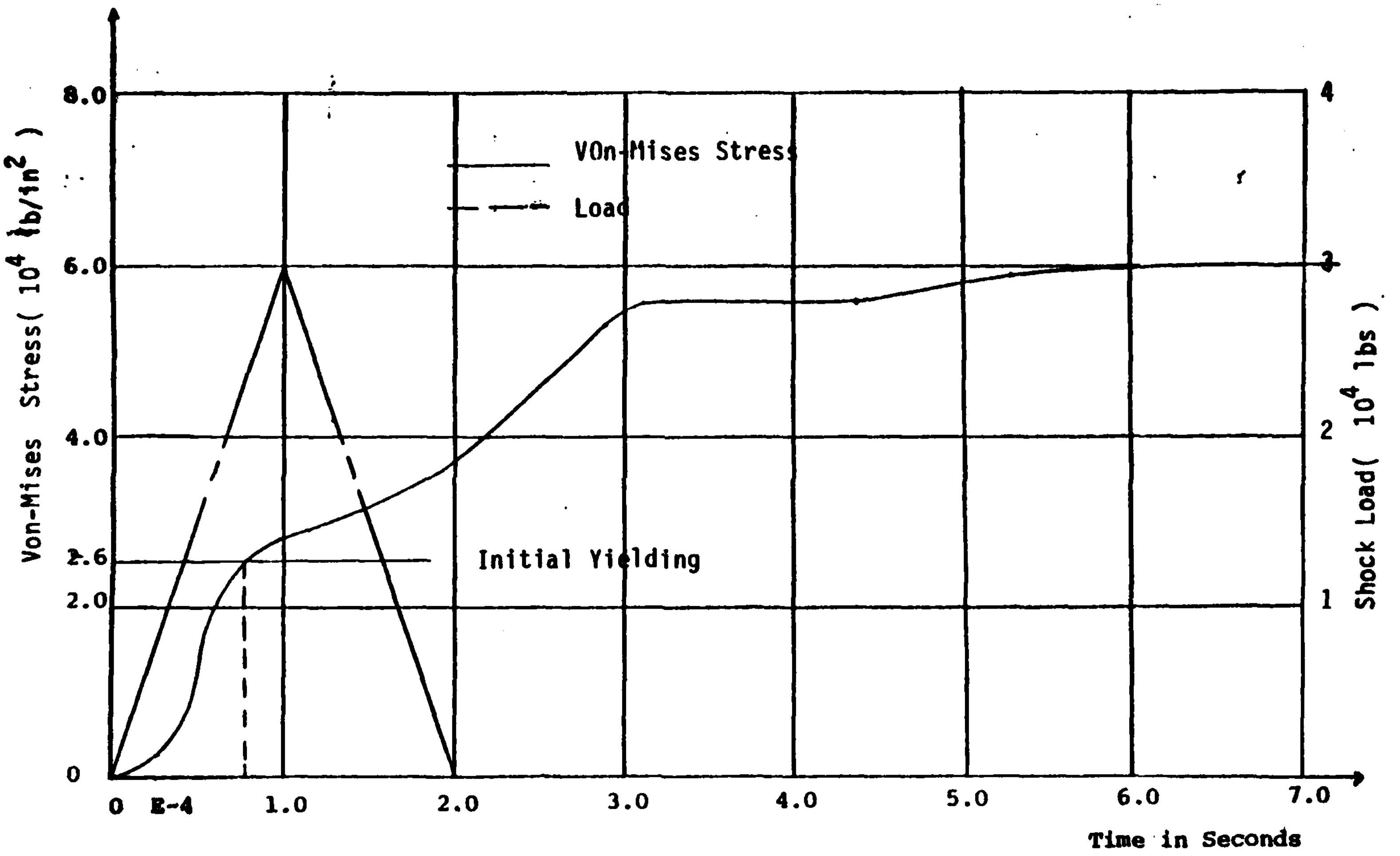


Figure 3.9. Time History Von-Mises Stress Response of QUAD4 Element 213.

IV. CONCLUSIONS AND RECOMMENDATIONS

The state-of-the-art literature review revealed that the skirt plate is very effective to absorb initial explosion energy before the shock loading reaches the main armor. The material of the armor must possess the high hardness to prevent the severe damage and the high ductility to minimize the spalling. The composite materials may serve more effectively than the conventional material to minimize the damages against the powerful modern projectiles.

The non-linear finite element analysis of the plate subjected to the air shock loading verifies the plastic hinge line formation and in-plane stretching inducing snap-through collapse. For the short duration shock loading, the maximum deformation occurs after the termination of loading, and the velocity reaches the maximum at the termination of shock. The Von-Mises stress is highly non-linear due to the material non-linearity. For the non-linear analysis using MSC/NASTRAN, TSTEPNL bulk data card is found to be the most important card which controls the accuracy and the stability of non-linear calculation.

To insure the convergence of solutions, convergence limit in the TSTEPNL card in the bulk data deck should be considered. If a program was run with big convergence limit, the solution will be gotten rapidly with small iteration steps but it is

not accurate and large time steps can't be taken. On the contrary, if the program was run with small convergence limit, the solution will be accurate but it is gotten slowly with large iteration steps. Thus, it is expensive and anyway large time steps can't be taken too. Thus, compromise should be taken to run a large time steps. For example, if one non-linear transient problem is needed total 700 time steps to get the solutions, the following procedure is recommended. In the first subcase, the program is iterated with smaller convergence limit, 10*E-7 to get more accurate solution and in the second subcase, the program is run with limit, 10*E-5, and in the third subcase, the program is iterated with convergence limit, 10*E-4.

Consequently, the total 700 time step will be calculated successively.

The sensitivity studies on shock period and amplitude is suggested to understand their effects on plate responses.

APPENDIX A

THE COMMAND TO OPERATE DATA BASE

****THE COMMAND TO ERASE THE DATA BASE NAMED "MSS.S277OP.NODE"

```
//ERASE JOB (2770,0252),NASTRAN,CLASS=A
//*MAIN ORG=NPGVM1.277OP
// EXEC PGM=IEFER14
//SYSPRINT DD SYSOUT=A
//DD1 DD DSN=MSS.S2770.NODE,DISP=(OLD,DELETE)
//
```

****THE COMMAND TO FLOT FROM THE DATABASE NAMED "MSS.S2770.PPLOT"

```
//LEEPLCT     JOB    (2770,0252),NASTRAN,CLASS=C
//*MAIN ORG=NPGVM1.2770P
//*FORMAT PR,DDNAME=SYSVECTR,DEST=LOCAL
//           EXEC NASTPLOT,PLTDSN='MSS.S2770.PPLOT'
```

APPENDIX B

DATA DECK FOR PROGRAM

GENERAL DESCRIPTION OF DATA DECK

The input deck begins with the required resident operating system control cards. The type and number of these cards will vary with the installation. Instructions for the preparation of these control cards are given in Section 7.6 of the MSC/NASTRAN Application Manual.

The operating system control cards are followed by the MSC/NASTRAN Data Deck, which consists of the following three sections:

1. Executive Control Deck
2. Case Control Deck
3. Bulk Data Deck

The Executive Control Deck and the Case Control Deck both have free-field formats. Only columns 1 through 72 are used for data. Any information in columns 73 through 80 may appear in the printed echo, but the data will not be used by the program. As explained in Section 2.4.1, limited use is made of the data in columns 73 through 80 for the Bulk Data Deck. If the last character on a card is a comma (not necessarily in column 72), the next card is a continuation of this physical card. Any number of continuation cards may be specified, and together they form a logical card.

The NASTRAN card is used to change the default values for certain operational parameters, such as buffer size or the number of data lines printed per page. More than one NASTRAN card may be present. NASTRAN cards are optional, but, if present, they must be the first cards of the data deck. The NASTRAN card is a free-field card (similar to cards in the Executive Control Deck). Its format is as follows:

$$\text{NASTRAN keyword}_1 = \text{value, keyword}_2 = \text{value, ...}$$

An alternate format is:

$$\text{NASTRAN keyword}_1 = \text{value}$$
$$\text{NASTRAN keyword}_2 = \text{value}$$

Input Data Card EGRID Grid Point Position

Description: Defines the position of a geometric grid point of the structural model

Format and Example:

1	2	3	4	5	6	7	8	9	10
EGRID	ID	CP	X1	X2	X3				
EGRID	2	3	1.0	2.0	3.0				

Field	Contents
ID	Grid point identification number (Integer > 0)
CP	Identification number of coordinate system in which the position of the grid point is defined (Integer $\geq$ 0 or blank)
X1,X2,X3	Position of the grid point in coordinate system CP (Real or Blank)

Remarks: 1. The meaning of X1, X2, and X3 depends on the type of coordinate system, CP, as follows: (see CØRDi card descriptions)

Type	X1	X2	X3
Rectangular	X	Y	Z
Cylindrical	R	θ(degrees)	Z
Spherical	R	θ(degrees)	ϕ(degrees)

2. The EGRID card is used in MSGMESH to define curved edges and for other special purposes (see Part I, Section 3.0). It is similar to a GRID card, except that it will not be processed by MSC/NASTRAN.

3. Entries in fields 7, 8 and 9 are not checked by MSGMESH.

Input Data Card GRIDG Linear and Higher Order Interpolation

Description: Defines a field of grid points and generates GRID cards

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRIDG	FID	CD/CI	PS	L	GA	GB	GC	SEID	
GRIDG	10	+0		18	-1	-2	-3		+G1
	M	GD	N	GE	GF	GG	GH	CI	
+G1	9	-4							+G2
	E1(AB)	E2(AB)	E1(BC)	E2(BC)	E1(CD)	E2(CD)	E1(DA)	E2(DA)	
+G2					6	5	8	7	
	E1(EF)	E2(EF)	E1(FG)	E2(FG)	E1(GH)	E2(GH)	E1(HE)	E2(HE)	
	E1(AE)	E2(AE)	E1(BF)	E2(BF)	E1(CG)	E2(CG)	E1(DH)	E2(DH)	

Field	Contents
FID	ID number of a GRIDG field (Integer, 1 ≤ FID ≤ 99). Must be unique for all GRIDG cards. When entry is negative, internal EGRID cards are generated.
CD/CI	Prescribes displacement and/or interpolation coordinate systems (Integer or blank). See Remarks 4 and 5.
PS	PS entry on generated GRID cards (any of the digits 1-6 with no imbedded blanks) (Integer ≥ 0 or blank)
L,M,N	Grid field dimensions when an entry, L, M, and/or N is positive. (See Figure 3.) Absolute value is a LID entry on a LIST input card, when an entry is negative.
SEID	SEID entry on generated GRID cards (Integer ≥ 0 or blank)
GA,...,GH	Grid point identification numbers, GIDs, of grid field vertex points (Integer ≠ 0 or blank). See Remarks 3 and 6.
CI	CP entry on generated GRID cards (Integer ≥ 0 or blank), and grid field interpolation coordinate system definition. See Remarks 4 and 5.
E1(XY)	ID number of edge grid point (closer to X) on side XY (Integer ≠ 0 or blank). See Remarks 3 and 6.
E2(XY)	ID number of edge grid point (closer to Y) on side XY (Integer ≠ 0 or blank). See Remarks 3 and 6.

(Continued)

Remarks: 1. See Part I, Sections 2 and 3 for discussions on the GRIDG input card.

2. Required data by type of field

Type	Required Data
LINE	FID, L, GA, GB
TRIA	FID, L, GA, GB, GC
QUAD	FID, L, M, GA, GB, GC, GD
HEX	FID, L, M, N, GA thru GH

Only the parent and first continuation card are applicable for linear interpolation.

3. Vertex and edge points are defined on GRID or EGRID input cards, or on GRID cards generated by *previously* processed GRIDG input cards. Field vertex points are automatically equivalenced to corresponding entries GA, ..., GH, when these entries are positive. GRID cards are generated only for active field grid points. See Part I, Section 10.1.

4. CD/CI entry may be used to *prescribe both the displacement coordinate system*, CD, and the interpolation coordinate system, CI. Both CD and CI are prescribed when the entry is positively signed. Only CD is prescribed when the entry is unsigned. Only CI is prescribed when the entry is negatively signed. The CI entry on the first continuation card may be used when both CD and CI exist and are different.

5. CI references a CID entry on a coordinate system definition input card. When CI is entered as 0, interpolation is in basic rectangular coordinates. When CI is not entered, interpolation is in the coordinate system that positions the field vertex and edge points. In this case, all vertex and edge points must be defined in the same coordinate system (CP entries on GRID and/or EGRID cards). See Part I, Section 3.1 and Table 2.

6. The ϕ interpolation point components, in spherical coordinate systems, or the θ interpolation point components, in cylindrical coordinate systems, may be offset by a $\pm 360°$ by appending a $\pm$S or a $\pm$C to grid point entries.

7. If an entry for GD is present in a TRIA field, grid point D replaces grid point C *in interpolating grid point positions from side* CA. Grid point D is usually defined by an EGRID card. M must be blank. See Part I, Section 3.5.

8. If both E1(XY) and E2(XY) are entered, the positions of generated grid points are determined by cubic interpolation from edge XY. If E2(XY) is blank, positions are determined by quadratic interpolation. If both E1(XY) and E2(XY) are blank, positions are determined by linear interpolation. Either none or one edge point, E(XY) may be specified for each edge of a TRIA field. E1(CD) positions a grid point on edge CA of TRIA fields. See Part I, Section 3.7.

9. Intermediate continuation cards cannot be omitted even if all entries are blank.

Input Data Card CGEN Generate Element Connection Bulk Data Cards, Form 1

Description: Generate element connection cards for element types listed under Remark 1

Format and Example:

1	2	3	4	5	6	7	8	9	10
CGEN	TYPE	FEID	PID	FID	DIR	TH	EIDL	EIDH	
CGEN	QUAD4	100	10	1					+C2
	TA	TB	TC	TD					
+C2	0.002	0.002	0.001	0.001					

Field	Contents
TYPE	Any of the mnemonics listed under Remark 1
FEID	The absolute value of FEID is the element identification number, EID, of first element in element set (Integer $\neq$ 0). See Remark 4.
PID	ID of an element property card or PGEN card (Integer > 0 or blank). Must be unique with respect to all other property card IDs and PGEN IDs. See Remark 5.
FID	ID of associated grid point field defined on a GRIDG or GRIDU card
DIR	One of the entries L, M, or N (Default entry is L). Direction of elements in the field. See Table 4 of Part I, Section 7.1.
TH	Material property orientation specification (Real or Blank; or Integer $\geq$ 0 and less than 1,000,000). If Real or Blank, specifies the material property orientation angle in degrees. If integer, the orientation of the material x-axis is along the projection onto the plane of the element of the x-axis of the co-ordinate system specified by the integer value.
EIDL	ID of element, below which no element connection cards are generated (Integer > 0 or blank)
EIDH	ID of element, above which no element connection cards are generated (Integer > 0 or blank)
TA,TB,TC,TD	Thickness of corner points of QUAD and TRIA fields when TYPE is TRIA3, TRIA6, QUAD4 or QUAD8 (Real or Blank). See Remark 6.

Remarks: 1. Element types: RØD, PLØTEL, CFTUBE, TUBE, TRIA3, TRAPRG, TRIARG, TRIA6, TRIM6, TRIAX6, QUAD4, SHEAR, QUAD8, HEXA1, HEXA2, HEXA8, HEXA20 and HEX20. The mnemonics HEXA8 and HEXA20 refer to HEXA elements with 8 or 9 through 20 nodes, respectively.

(Continued)

2. Elements are tabulated by class in Table 3, of Part I, Section 7.0. Line class elements may be generated in all field types. Tria3 and Tria6 class elements may be generated in TRIA and QUAD fields. Quad4 and Quad8 class elements may be generated in TRIA, QUAD and HEX fields. Only QUAD4 and QUAD8 element types are valid in TRIA fields. TRIA3 and TRIA6 elements are generated, in this case, along the field edge corresponding to the element direction. Hex8 and Hex20 class elements may only be generated in HEX fields.

3. MSGMESH automatically generates PENTA elements in place of HEXA and HEX20 elements, when adjacent element edges would have the same grid point identifiers. TRIA6 elements replace QUAD8 elements and TRIA3 elements replace QUAD4 elements, when adjacent element vertices would have the same grid point identifiers. Otherwise, MSGMESH suppresses the generation of an element which would reference identical grid point identifiers. Elements are generated only when all vertex points exist. Deleted midside nodes suppress the generation fo TRIM6 and TRIAX6 elements.

4. EIDs are incremented when the FEID entry is positive and decremented when the FEID entry is negative.

5. The PID entry may be blank for those elements whose element connection card permit a blank property ID.

6. Element thicknesses may be generated for TRIA3, TRIA6, QUAD4 and QUAD8 elements located in TRIA and QUAD fields. Interpolation from the thicknesses at the field vertices is based on field topologies with equal spacings of thicknesses for both GRIDG and GRIDU fields. Unequal spacings of thicknesses are defined for GRIDG fields specified with unequal spacings of grid points.

Input Data Card MAT1 Material Property Definition, Form 1

Description: Defines the material properties for linear, temperature-independent, isotropic materials

Format and Example:

1	2	3	4	5	6	7	8	9	10
MAT1	MID	E	G	NU	RHØ	A	TREF	GE	
MAT1	17	3.+7		0.33	4.28	6.5-6	5.37+2	0.23	ABC
	ST	SC	SS	MCSID					
+BC	20.+4	15.+4	12.+4	1003					

Field	Contents
MID	Material identification number (Integer > 0)
E	Young's modulus (Real or blank)
G	Shear modulus (Real or blank)
NU	Poisson's ratio (-1.0 < Real $\leq$ 0.5 or blank)
RHØ	Mass density (Real)
A	Thermal expansion coefficient (Real)
TREF	Thermal expansion reference temperature (Real)
GE	Structural element damping coefficient (Real)
ST,SC,SS	Stress limits for tension, compression, and shear (Real). (Used only to compute margins of safety in certain elements; they have no effect on the computational procedures.)
MCSID	Material Coordinate System identification number (Integer $\geq$ 0 or blank)

Remarks:

1. The material identification number must be unique for all MAT1, MAT2, MAT3 and MAT9 cards.
2. MAT1 materials may be made temperature dependent by use of the MATT1 card.
3. The mass density, RHØ, will be used to automatically compute mass for all structural elements.
4. Weight density may be used in field 6 if the value 1/g is entered on the PARAM card WTMASS, where g is the acceleration of gravity (see Section 3.1.5).
5. MCSID must be nonzero if the CURV module is used to calculate stresses or strains at grid points on plate and shell elements only.
6. To obtain the damping coefficient, GE, multiply the critical damping ratio C/C_0, by 2.0.

(Continued)

7. Either E or G must be specified (i.e., nonblank).

8. If any one of E, G, or NU is blank, it will be computed to satisfy the identity $E = 2(1+NU)G$; otherwise, values supplied by the user will be used. This calculation is only made for initial values of E, G, and NU.

9. If E and NU or G and NU are both blank, they will both be given the value 0.0.

10. Implausible data on one or more MAT1 cards will result in a warning message. Implausible data is defined as any of $E < 0.0$, $G < 0.0$, $0.5 < NU < 0.0$, or $\left|1 - \frac{E}{2(1+NU)G}\right| > 0.01$ (except for cases covered by Remark 9).

Input Data Card MATS1 Material Stress Dependence

Description: Specifies table references and material properties which are stress-dependent for use in material nonlinearity applications. This card will be activated if MAT1 with the same MID is being used in the material nonlinear solution sequence (66).

Format and Example:

1	2	3	4	5	6	7	8	9	10
MATS1	MID	R1	TYPE	B	YF	HR	LIMIT1		
MATS1	17	28	PLASTIC		2	3	2.+4		+ABC
	LIMIT2								
+ABC									

Field	Contents
MID	Identification number of a MAT1 card (Integer > 0)
R1	Identification number of a TABLES1 card (Integer $\geq$ 0)
TYPE	Type of material nonlinearity (BCD) NLELAST (Nonlinear elastic) or PLASTIC (Plasticity theory)
B	Work hardening slope (slope of stress vs. plastic strain) in units of stress (Real). For elastic-perfectly plastic cases, B = 0.0. For more than a single slope in the plastic range, the stress-strain data must be supplied in a TABLES1 card referenced in field 3. See Remarks 1 and 2.
YF	Yield function (Integer); one of the following values: (Default = 1) 1 (von Mises) 2 (Tresca) 3 (Mohr-Coulomb) 4 (Drucker-Prager)
HR	Hardening Rule (Integer); one of the following values: (Default = 1) 1 (Isotropic) 2 (Kinematic) 3 (Combined isotropic and kinematic hardening)
LIMIT1	Parameter used in the yield function specification (Real). See Remark 4.
LIMIT2	Parameter used in the yield function specification for yield functions 3 and 4 (Real). See Remark 4.

Remarks: 1. If type = NLELAST, the stress-strain data given in the TABLES1 card will be use determine the stress for a given value of strain. The values B, YF, HR, LIM and LIMIT2 will not be used in this case.

2. If type = PLASTIC, either the table identification, R1, or the work harder slope, B, may be given but not both. If the table ID is omitted, the hardening slope, B, specified in field 5 is defined as

$$B = \frac{f'}{1 - \frac{f'}{E}} \quad \text{or} \quad f' = \frac{B}{1 + \frac{B}{E}}$$

where E is the elastic modulus and f' is the slope of the uniaxial stress-str curve in the plastic region.

3. If R1 is given, TABLES1 entries of stress-strain data must conform to the follow rules:

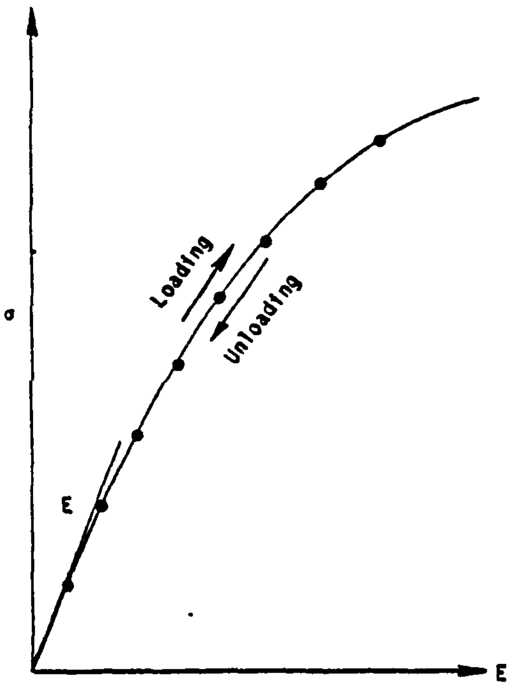
a. If type = NLELAST, the curve must pass through origin (x_i=0., y_i=0., for s value of i). This option is valid only for line elements.

b. If type = PLASTIC, only data for the first quadrant need be supplied. Th are two options available to specify the data. In case 1 (defined as FØR in the TABLES1 card) the first point is at the origin, the second point is the yield stress given in field 8 of the MATS1 card. The slope of the l joining the origin to the yield stress must be equal to the value of E gi on the MAT1 Bulk Data card. In case 2 (defined as FORM=1 in the TABL card) the slopes of the curve in the plastic range are supplied. See TABLES1 card description for additional details.

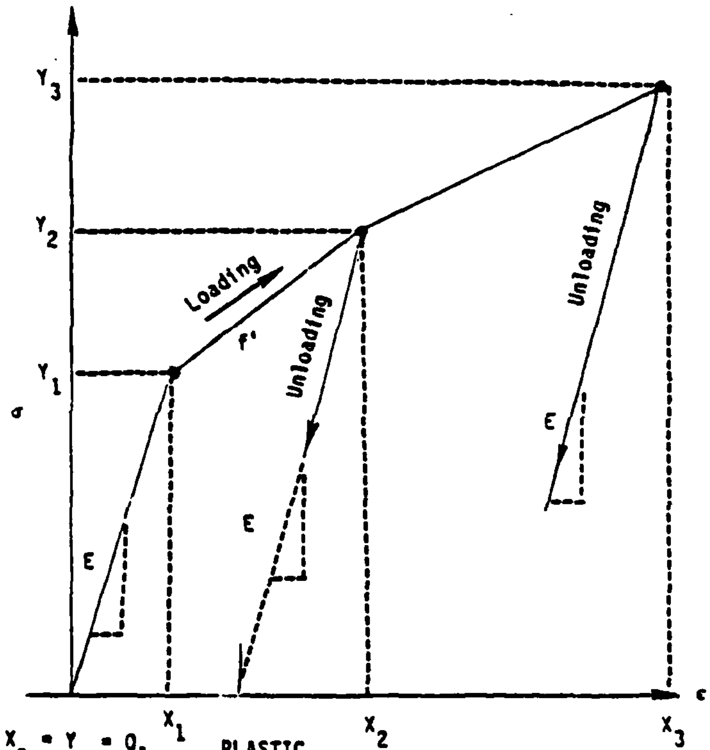
4. LIMIT1 and LIMIT2 are parameters used in the yield function definition as follows

Yield Function	LIMIT1	LIMIT2
von Mises (1) or Tresca (2)	Yield stress in tension, σ_y	Not used
Mohr-Coulomb (3) or Drucker-Prager (4)	Cohesion,c (in stress units)	Angle of internal friction ϕ (in degree

5. See Section 2.14.1.2 in the MSC/NASTRAN Application Manual for a detail description of yield function and hardening rules.



NLELAST



PLASTIC

Input Data Card TABLES1 Material Property Table, Form 1

Description: Defines a tabular function for stress-dependent material properties such as the stress-strain curve and creep parameters

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLES1	ID	I							
TABLES1	32								ABC
	x_1	y_1	x_2	y_2	x_3	y_3	x_4	y_4	
+BC	0.0	0.0	.01	10000.	.02	15000.	ENDT		

(etc.)

Field	Contents
ID	Table identification number (Integer > 0).
I	Not used
x_i, y_i	Tabular entries (Real)

Remarks:

1. The x_i must be in either ascending or descending order but not both.
2. Jumps between two points ($x_i = x_{i+1}$) are allowed, but not at the end points.
3. At least two entries must be present.
4. Any x-y entry may be ignored by placing the BCD string SKIP in either of the two fields used for that entry.
5. The end of the table is indicated by the existence of the BCD string ENDT in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag ENDT.
6. TABLES1 is used to input a curve in the form of

$$\boxed{Y = Y_T(X)}$$

where X is input to the table and Y is returned. The table look-up $y_T(x)$, $x = X$, is performed using linear interpolation within the table and linear extrapolation outside the table using the last two end points at the appropriate table end. At jump points the average $y_T(x)$ is used.

Input Data Card PLØAD2 Pressure Load on a Two-Dimensional Structural Element

Description: Defines a uniform static pressure load applied to two-dimensional elements. Only ~~QUAD4, SHEAR~~, TRIA3, or TRIAX6 elements may have a pressure load applied to them via this card.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PLØAD2	SID	P	EID	EID	EID	EID	EID	EID	
PLØAD2	21	-3.5		4	16		2		

Alternate Form:

PLØAD2	SID	P	EID1	"THRU"	EID2				
PLØAD2	1	30.4	16	THRU	48				

Field	Contents
SID	Load set identification number (Integer > 0)
P	Pressure value (Real)
EID EID1 EID2	Element identification number (Integer > 0; EID1 < EID2)

Remarks:
1. EID must be 0 or blank for omitted entries.
2. Load sets must be selected in the Case Control Deck (LØAD=SID) to be used by MSC/NASTRAN.
3. At least one positive EID must be present on each PLØAD2 card.
4. If the alternate form is used, all elements EID1 through EID2 must be two-dimensional.
5. The direction of the pressure is computed according to the right-hand rule using the grid point sequence specified on the element card. Refer to the PLØAD card.
6. All elements referenced must exist.
7. Continuation cards are not allowed.

Input Data Card NLPARM Parameters for Nonlinear Analysis Control

Description: Defines a set of parameters for nonlinear analysis iteration strategy

Format and Example:

1	2	3	4	5	6	7	8	9	10
NLPARM	ID	INC	DT	KMETHØD	KSTEP	MAXITER	CØNV	INTØUT	
NLPARM	15	5		AUTØQN			PW		+NL1
	EPSU	EPSP	EPSW	MAXDIV	MAXQN	MAXLS	FSTRESS		
+NL1	1.0E-3	1.0-4	1.0-5	1	20	8	.02		

Field	Contents
ID	Identification Number (Integer > 0)
INC	Number of increments (Integer > 0)
DT	Incremental time interval for creep analysis (Real $\geq$ 0) (Default = 0.; no creep)
KMETHØD	Method for controlling tangent stiffness updates (BCD = AUTØ,ITER,SEMI,LSQN,AUTØQN, or SEMIQN) (No default). See Remark 5.
KSTEP	Number of iterations before a matrix update. Used only for ITER and LSQN methods. (Integer $\geq$ 0 or blank) (Default = 1)
V63 MAXITER	Limit on total iterations for each load increment (Integer $\neq$ 0) (Default = 20)
CØNV	Flags to select convergence tests (BCD = U, P, W, or any combination of the letters) (Default = W). See Remarks 3 and 4.
INTØUT	Intermediate output flag (BCD = YES or NØ) (Default = YES). See Remark 6.
EPSU,EPSP, EPSW	Error tolerance limits for determining convergence (Real > 0.0) (Defaults = 1.0E-2, 1.0E-3, 1.0E-4, respectively)
MAXDIV	Limit on diverging iterations (Integer > 0) (Default = 1)
MAXQN	Maximum number of Quasi-Newton correction vectors to be saved on the data base (Integer $\geq$ 0) (Default = 10)
MAXLS	Maximum number of linear search operations per vector iteration (Integer $\geq$ 0) (Default = 8)
FSTRESS	Fraction of effective stress ($\bar{\sigma}$) used to determine the subincrement size in the material routines (0. < Real < 1.0) (Default = 0.15). See Remark 9.

(Continued)

Remarks: 1. The NLPARM Bulk Data card is requested by the Case Control card NLPARM = ID. Each solution subcase requires a loading condition and an NLPARM request.

2. In case of static analysis (DT = blank), INC is the number of equal subdivisions of the net load change defined for the SUBCASE. Applied loads, gravity loads, temperature sets, enforced displacements, etc., define the new loading condition. The differences from the previous case are divided by INC to define the incremental values. In case of creep analysis (DT > 0.), INC is the number of time step increments.

3. The test flags (U,P,W) and the error limits (EPSU, etc.) define the convergence criteria (U = Displacement error test, P = Load equilibrium error test, W = Work error test). If the internally calculated error fractions are less than the requested limits, the iteration stops, the results are processed, and the program continues to the next load increment or subcase. All requested error criteria must be satisfied for a "convergent solution".

4. If convergence does not occur for a particular load increment, the number of iterations is limited to MAXITER. If MAXITER is a positive number, the results will be processed and the program will continue with the next load increment. If MAXITER is a negative value, the solution will terminate if convergence is not achieved.

5. The basic nonlinear solution methods are the "QFGS" Quasi-Newton and modified "Newton-Raphson" processes whereby the out-of-balance nonlinear loads are measured and recycled to solve for improved displacements. The convergence of this iteration process is generally improved by either performing "line searches" or by frequent updates to the "tangent stiffness matrix" to account for current plastic and geometric effects. However, the matrix updates may be relatively costly and may be detrimental if the estimates are far from the correct answer. Thus, the user is given the following KMETHØD options to provide control over a large range of problem types.

   a. If the AUTØ option is selected, the program will automatically select the most efficient strategy based upon convergence rates. At each step the number of iterations required to converge is estimated. If this exceeds the MAXITER limit, or if the CPU time exceeds the time to perform a stiffness matrix update, the module will perform a stiffness update. If divergence occurs for MAXDIV successive iterations, a stiffness update is also performed.

   b. If the SEMI option is selected, for each load increment the program will: (1) perform a single displacement iteration based upon the new load; (2) update the stiffness matrix for the estimated geometry and material properties; and (3) resume the normal AUTØ iteration method.

   c. If the ITER option is selected, the stiffness matrix will be updated only after each KSTEP iteration. The count is reset to zero for each new matrix or load step.

   d. If one of the AUTØQN, SEMIQN, or the LSQN options is selected the "Quasi-Newton" and "Line Search" procedures are used. Basically the line search (LS) will scale the displacement increment vector to minimize the error at each iteration. If the line search provides a substantial improvement, the Quasi-Newton (QN) operations use the local tangent of the error to correct the tangent matrix solution for subsequent iterations. Otherwise the operations behave much like the AUTØ, SEMI, and ITER options.

(Continued)

6. Output requests for ELFØRCE and STRESS made in Case Control will be processed if INTØUT = YES (the default value). If INTØUT = NØ, these output requests are processed for only the last load factor in a subcase. Requests for DISP printout and structure plots are also processed during the nonlinear iteration if PARAM, NLDISP, 1 is provided in the Bulk Data deck.

7. If a diverging solution is encountered for MAXDIV successful iterations, the AUTØ, AUTØQN, SEMI, and SEMIQN options will perform a tangent stiffness update. If, after the stiffness update, the solution is still diverging, the program terminates. For ITER and LSQN options, diverging cases cause immediate termination.

8. The unit of the incremental time interval under DT field must be consistent with the unit used on the CREEP card to define the creep characteristics. Total creep time for the subcase may be found from DT multiplied by the value in the INC.

9. The number of subincrements in the material routines (elastoplastic and creep) are determined such that the subincrement size is approximately FSTRESS * $\bar{\sigma}$.

   FSTRESS is also used to establish a tolerance for elastoplastic material in the material routine, i.e.,

$$\delta \text{ in yield function} < \text{FSTRESS} * \text{yield stress} \quad .$$

   If the limit is exceeded at the converging state, the program will exit with a fatal error message. Otherwise the stress state is adjusted to the current yield surface, resulting in $\delta = 0$.

Input Data Card SPCG Constraint Set Generator, Standard Form

Description: Generates SPC1 cards that constrain a subset of grid points in a grid point field

Format and Example:

1	2	3	4	5	6	7	8	9	10
SPCG	SID	FID	C	D1	D2				
SPCG	15	3	246	0002	0312				

Field	Contents
SID	ID number of single-point constraint set (Integer > 0)
FID	ID number of a GRIDG or GRIDU field
C	Component numbers (any combination of the digits 1-6 with no imbedded blanks) in the displacement coordinate system (CD entry on GRIDG card)
D1,D2	Location number pair of order-independent pivot points that define a subset of grid points in FID. See Part I, Section 2.5.

Remarks: 1. See Part I, Section 5.0 for a discussion on the SPCG input card.

2. SPC entries on generated SPC1 cards are made only for active grid points. See Part I, Section 10.1.

Input Data Card DLØAD Dynamic Load Combination (Superposition)

Description: Defines a dynamic loading condition for frequency response or transient response problems as a linear combination of load sets defined via RLØAD1 or RLØAD2 cards (for frequency response) or TLØAD1 or TLØAD2 cards (for transient response)

Format and Examples:

1	2	3	4	5	6	7	8	9	10
DLØAD	SID	S	S1	L1	S2	L2	S3	L3	
DLØAD	17	1.0	2.0	6	-2.0	7	2.0	8	+A
	S4	L4		-etc.-					
+A	-2.0	9							

-etc.-

Field	Contents
SID	Load set identification number (Integer > 0)
S	Scale factor (Real)
Si	Scale Factors (Real)
Li	Load set identfication numbers defined via card types enumerated above (Integer > 0)

Remarks: 1. The load vector being defined by this card is given by

$$\{P\} = S \sum_i S_i \{P_i\} \quad .$$

2. The Li must be unique.

3. SID must be unique from all Li.

4. Nonlinear transient loads may not be included; they are selected separately in the Case Control Deck.

5. Linear load sets must be selected in the Case Control Deck (DLØAD=SID) to be used by MSC/NASTRAN.

6. A DLØAD card may not reference a set identification number defined by another DLØAD card.

7. TLØAD1 and TLØAD2 loads may be combined only through the use of the DLØAD card.

8. RLØAD1 and RLØAD2 loads may be combined only through the use of the DLØAD card.

9. SID must be unique for all TLØAD1, TLØAD2, RLØAD1 and RLØAD2 cards.

Input Data Card TLØAD1 Transient Response Dynamic Load, Form 1

Description: Defines a time dependent dynamic load or enforced motion of the form

$$\{P(t)\} = \{A\ F(t - \tau)\}$$

for use in a transient response problem

Format and Example:

1	2	3	4	5	6	7	8	9	10
TLØAD1	SID	L	M	TYPE	TID				
TLØAD1	5	7	9	0	13				

Field	Contents
SID	Set identification number (Integer > 0)
L	Identification number of DAREA card set or a static load card set or a thermal load set (in heat transfer analysis) which defines A (Integer > 0)
M	Identification number of DELAY card set which defines τ (Integer $\geq$ 0)
TYPE	Defines the nature of the dynamic excitation (Integer 0, 1, 2, 3 or blank). (See Remark 2.)
TID	Identification number of TABLEDi card which gives $F(t - \tau)$ (Integer > 0)

Remarks:

1. If M is zero, τ will be zero.

2. The nature of the dynamic excitation is defined in field 5 in accordance with the following table.

Integer	Excitation Function
0 or blank	Force or Moment
1	Enforced Displacement
2	Enforced Velocity
3	Enforced Acceleration

See Section 2.7 of the MSC/NASTRAN Application Manual regarding the use of the enforced motion options. Note that "large masses" must be used for enforced motion. For heat transfer problems, Field 5 must be blank.

(Continued)

3. Dynamic load sets must be selected in the Case Control Deck (DLØAD=SID) to be used by MSC/NASTRAN.

4. TLØAD1 loads may be combined with TLØAD2 loads only by specification on a DLØAD card. That is, the SID on a TLØAD1 card may not be the same as that on a TLØAD2 card.

5. SID must be unique for all TLØAD1, TLØAD2, RLØAD1 and RLØAD2 cards.

6. Field 3 may reference sets containing QHBDY, QBDY1, QBDY2, QVECT, and QVØL cards when using the heat transfer option.

7. If the heat transfer option is used, the referenced QVECT data card may also contain references to functions of time, and therefore A may be a function of time.

8. Fourier analysis will be used if this is selected in an aeroelastic response problem.

Input Data Card <u>LSEQ</u> Static Load Set Definition

Description: Defines a sequence of static load sets to be applied to the structural model. The load sets may be referenced by dynamic load cards.

Format and Example:

1	2	3	4	5	6	7	8	9	10
LSEQ	SID	DAREA	LID	TID					
LSEQ	100	200	1000	1001					

Field	Contents
SID	Set identification of the set of LSEQ cards (Integer > 0)
DAREA	The DAREA set identification assigned to this static load vector (Integer > 0)
LID	Load set identification number of a set of static load cards (Any card that may be referenced by the LØAD Case Control card) (Integer > 0 or blank)
TID	Set identification of a thermal load set (Any card that may be referenced by the TEMP(LØAD) Case Control card) (Integer > 0 or blank)

Remarks:

1. The above cards will not be used unless selected in the Case Control Deck with a LØADSET card.
2. This card is available only in superelements and in Solution Sequences 26, 27, 30 and 31.
3. The number of static load vectors created for each superelement is the number of unique DAREA IDs on all LSEQ cards in the bulk data.
4. The DAREA identification assigned to the static load vectors may be referenced by RLØAD1, RLØAD2, TLØAD1 and TLØAD2 cards.
5. Element data recovery for thermal loads is not currently implemented in dynamics.
6. DAREA set identification numbers should be unique with respect to all static load set identification numbers.

AD-A140 491 NON-LINEAR TRANSIENT RESPONSE OF FLAT PLATE TO AIR SHOCK WAVE(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA J N LEE DEC 83

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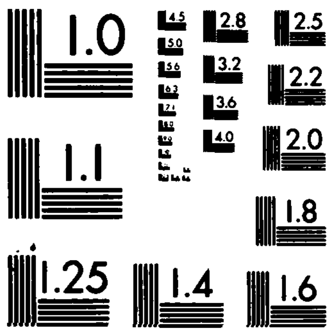

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Input Data Card <u>TABLED1</u> Dynamic Load Tabular Function, Form 1

Description: Defines a tabular function for use in generating frequency-dependent and time-dependent dynamic loads

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLED1	ID								
TABLED1	32								+ABC
	x_1	y_1	x_2	y_2	x_3	y_3	x_4	y_4	
+BC	-3.0	6.9	2.0	5.6	3.0	5.6	ENDT		

- etc.-

Field	Contents
ID	Table identification number (Integer > 0)
x_i, y_i	Tabular entries (Real)

Remarks: 1. The x_i must be in either ascending or descending order but not both.

2. Jumps between two points $(x_i = x_{i+1})$ are allowed, but not at the end points.

3. At least two entries must be present.

4. Any x-y entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.

5. The end of the table is indicated by the existence of the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".

6. Each TABLED1 mnemonic infers the use of a specific algorithm. For TABLED1 type tables, this algorithm is

$$\boxed{Y = y_t(X)}$$

where X is input to the table and Y is returned. The table look-up $y_T(x)$, $x = X$, is performed using linear interpolation within the table and linear extrapolation outside the table using the last two end points at the appropriate table end. At jump points the average $y_T(x)$ is used. There are no error returns from this table look-up procedure.

7. Linear extrapolation is not used for Fourier Transform methods. The function is zero outside the range.

Input Data Card TSTEPNL Time Step and Nonlinear Solution Controls

Description: Provides parametric controls and data for Nonlinear Transient Analysis

Format and Example:

1	2	3	4	5	6	7	8	9	10
TSTEPNL	ID	NDT	DT	NØ	METHØD	KSTEP	MAXITER	CØNV	
TSTEPNL	250	40	.0015	5	AUTØ		5	P	+NL1
	EPSU	EPSP	EPSW	MAXDIV	MAXQN	MAXLS	FSTRESS		
+NL1		.01		1	20	6	.02		

Field	Contents
ID	Identification number (Integer > 0)
NDT	Number of time steps of value DT(i) (Integer $\geq$ 2)
DT	Time increment (Real > 0.0)
NØ	Skip factor for output (every NØth step will be saved for output) (Integer > 0)
METHØD	Method for controlling iterations and tangent matrix updates (BCD = AUTØ or TSTEP) (No default)
KSTEP	Number of steps before a matrix update (Integer $\geq$ 0) (Default = 0)
MAXITER	Limit on total iterations for each time increment (Integer > 0) (Default = 2)
CØNV	Flags to select convergence tests (BCD = U, P, W, or any combination of the letters or blank)
EPSU,EPSP,EPSW	Error tolerance limits for determining convergence (Real > 0.0) (Defaults = 1.0E-2, 1.0E-3, 1.0E-4, respectively)
MAXDIV	Limit on the number of diverging iterations at each time and on diverging time steps (Integer > 0) (Default = 2)
MAXQN	Maximum number of Quasi-Newton correction vectors to be saved on the data base (Integer $\geq$ 0) (Default = 20)
MAXLS	Maximum number of Line Search iterations for LSQN option (Integer $\geq$ 0) (Default = 2)
FSTRESS	Fraction of effective stress $(\bar{\sigma})$ used to determine the subincrement size in the material routines (0. < Real < 1.0) (Default = 0.15). See Remark 10.

(Continued)

TSTEPNL (Cont.)

Remarks: 1. The TSTEPNL Bulk Data card is selected by the Case Control card TSTEPNL = ID. Each subcase (residual superelement solutions only) requires a TSTEPNL card and either applied loads via TLØAD1 data or initial values from a previous subcase. Multiple subcases are assumed to occur sequentially in time with the initial values of time and displacement conditions of each subcase defined by the end conditions of the previous subcase.

2. DT, NDT, NØ are the time increments, Δt, the total number of steps N_t, and the output interval, n_0, respectively. The value of time, T_n, at each increment n will be

$$t_n = t_0 + n\Delta t \qquad n = 0, 1, \ldots, N,$$

where t_0 is the initial value of time which corresponds to the last step from the previous subcase.

3. For printing and plotting the solution, data will be output at steps $n = 0, n_0, 2n_0, \ldots N$. The Case Control card ØTIME may also be used to control the output points.

4. The basic solution method is the "Newmark Beta" transient numerical method along with the "Newton-Raphson" method for controlling nonlinear effects. Equilibrium solutions with respect to inertial, damping, elastic, and nonlinear loads are obtained at each time step much the same as in the statics case.

The KMETHØD options provide the user with three optional nonlinear iteration methods. These are:

<u>AUTØ</u> provides for automatic stiffness matrix updates to improve poor convergence. The KSTEP value is ignored.

<u>TSTEP</u> provides for a matrix update at every KSTEPth increment of time (typically a large number).

5. The stiffness matrix is always updated for a new subcase or restart. Only one update is allowed for each time step and the iteration process returns to the previous time step after an update.

6. MAXITER defines the number of static nonlinear load iterations (corrections) to be performed at each time step. At least two iterations are necessary to determine the convergence of the displacements (see below).

7. The test flags (U,P,W) and the error limits (EPSU, etc.) define the convergence criteria (U = Displacement error test, P = Load equilibrium error test, W = Work error test). If the internally calculated error fractions are less than the requested limits, the iteration stops, the results are processed, and the program continues to the next time step or subcase.

8. If no tests are requested or no convergence occurs, the number of iterations is limited to MAXITER. The results will be processed and the program will continue with the next time step.

9. MAXQN provides the control over diverging solutions. At each time step, the solution is allowed to diverge until, at the MAXDIV iteration, a matrix update is requested. If the average convergence parameter $\bar{\lambda}_t$ indicates divergence for MAXDIV successive time steps, the transient solution stops and exits for data recovery.

10. The number of subincrements in the material routines (elastoplastic and creep) are determined such that the subincrement size is approximately FSTRESS * $\bar{\sigma}$.

    FSTRESS is also used to establish a tolerance for elastoplastic material in the material routine, i.e.,

    $$\delta \text{ in yield function} < \text{FSTRESS} * \text{yield stress} \quad .$$

    If the limit is exceeded at the converging state, the program will EXIT with a fatal error message. Otherwise the stress state is adjusted to the current yield surface, resulting in $\delta = 0$.

APPENDIX C

OUTPUT OF MSC/NASTRAN

```
                                                  DECEMBER  1, 1983  MSC/NASTRAN  8/ 1/83   PAG

    N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

ID NONLINEAR,TRANSIENT
SOL 59
TIME 59
CEND
```

```
                              C A S E   C O N T R O L   D E C K   E C H O
 CARD
 COUNT
   1      TITLE=NONLINEAR DEFORMATION WITH DYNAMIC LOADS
   2      SUBTITLE=TRANSIENT RESPONSE BY SHOCK WAVE LOAD.
   3      ECHO=SORT
   4      SET 1=20202,20203,20204,20304,20404
   5      SET 2=201,206,212,213,214,219,225
   6      SET 3=20000,20003,20005,20200,20400
   7      SDISP=1
   8      OLOAD=1
   9      SPCF=3
  10      ELST=2
  11      SEALL=ALL
  12      SPC=200
  13      LOADSET=77
  14      SUBCASE 1
  15      CLOAD=37
  16      TSTEPNL=45
  17      SUBCASE 2
  18      CLOAD=37
  19      TSTEPNL=46
  20      SUBCASE 3
  21      CLOAD=37
  22      TSTEPNL=47
  23      OUTPUT(XYPLOT)
  24      PLOTTER NAST
  25      $ CSCALE 1.3
  26      XTITLE=TIME IN SECS
  27      XGRID LINES=YES
  28      YGRID LINES=YES
  29      YTITLE=DISPLACEMENT GRID 20202
  30      XYPLOT SDISP RESP/20202(T3)
  31      YTITLE=VELOCITY GRID 20202
  32      XYPLOT SVELO RESP/20202(T3)
  33      YTITLE=DISPLACEMENT GRID 20101 20102 20202
  34      XYPLOT SDISP RESP/20101(T3),20102(T3),20202(T3)
  35      BEGIN BULK
              INPUT BULK DATA CARD COUNT =      115
```

S O R T E D   B U L K   D A T A   E C H O

CARD COUNT	. 1 ..	2 ..	3 ..	4 ..	5 ..	6 ..	7 ..	8 ..	9 ..	10 .
1-	CQUAD4	201	200	20000	20001	20101	20100			
2-	CQUAD4	202	200	20001	20002	20102	20101			
3-	CQUAD4	203	200	20002	20003	20103	20102			
4-	CQUAD4	204	200	20003	20004	20104	20103			
5-	CQUAD4	205	200	20004	20005	20105	20104			
6-	CQUAD4	206	200	20100	20101	20201	20200			
7-	CQUAD4	207	200	20101	20102	20202	20201			
8-	CQUAD4	208	200	20102	20103	20203	20202			
9-	CQUAD4	209	200	20103	20104	20204	20203			
10-	CQUAD4	210	200	20104	20105	20205	20204			
11-	CQUAD4	211	200	20200	20201	20301	20300			
12-	CQUAD4	212	200	20201	20202	20302	20301			
13-	CQUAD4	213	200	20202	20203	20303	20302			
14-	CQUAD4	214	200	20203	20204	20304	20303			
15-	CQUAD4	215	200	20204	20205	20305	20304			
16-	CQUAD4	216	200	20300	20301	20401	20400			
17-	CQUAD4	217	200	20301	20302	20402	20401			
18-	CQUAD4	218	200	20302	20303	20403	20402			
19-	CQUAD4	219	200	20303	20304	20404	20403			
20-	CQUAD4	220	200	20304	20305	20405	20404			
21-	CQUAD4	221	200	20400	20401	20501	20500			
22-	CQUAD4	222	200	20401	20402	20502	20501			
23-	CQUAD4	223	200	20402	20403	20503	20502			
24-	CQUAD4	224	200	20403	20404	20504	20503			
25-	CQUAD4	225	200	20404	20405	20505	20504			
26-	DLOAD	37	1.0	1.0	7	1.0	6	1.0	5	
27-	GRID	20000		0.0	0.0	0.0				
28-	GRID	20001		4.	0.0	0.0				
29-	GRID	20002		8.	0.0	0.0				
30-	GRID	20003		12.	0.0	0.0				
31-	GRID	20004		16.	0.0	0.0				
32-	GRID	20005		20.	0.0	0.0				
33-	GRID	20100		0.0	4.	0.0				
34-	GRID	20101		4.	4.	0.0				
35-	GRID	20102		7.99999	4.	0.0				
36-	GRID	20103		12.	4.	0.0				
37-	GRID	20104		16.	4.	0.0				
38-	GRID	20105		20.	4.	0.0				
39-	GRID	20200		0.0	8.	0.0				
40-	GRID	20201		4.	8.	0.0				
41-	GRID	20202		7.99999	8.	0.0				
42-	GRID	20203		12.	8.	0.0				
43-	GRID	20204		16.	8.	0.0				
44-	GRID	20205		20.	8.	0.0				
45-	GRID	20300		0.0	12.	0.0				
46-	GRID	20301		4.	12.	0.0				
47-	GRID	20302		7.99999	12.	0.0				
48-	GRID	20303		12.	12.	0.0				
49-	GRID	20304		16.	12.	0.0				
50-	GRID	20305		20.	12.	0.0				

```
                                S O R T E D   B U L K   D A T A   E C H O
 CARD
 COUNT        .   1  ..   2  ..   3  ..   4  ..   5  ..   6  ..   7  ..   8  ..   9  ..  10  .
   51-        GRID    20400           0.0     16.     0.0
   52-        GRID    20401           4.      16.     0.0
   53-        GRID    20402           8.      16.     0.0
   54-        GRID    20403           12.     16.     0.0
   55-        GRID    20404           16.     16.     0.0
   56-        GRID    20405           20.     16.     0.0
   57-        GRID    20500           0.0     20.     0.0
   58-        GRID    20501           4.      20.     0.0
   59-        GRID    20502           8.      20.     0.0
   60-        GRID    20503           12.     20.     0.0
   61-        GRID    20504           16.     20.     0.0
   62-        GRID    20505           20.     20.     0.0
   63-        LSEQ    77      63      91
   64-        LSEQ    77      61      71
   65-        LSEQ    77      62      81
   66-        MAT1    65      3.0E+7          .3      7.33E-4                 0.01
   67-        MATS1   65      40      PLASTIC         1       1       2.6E+4
   68-        PARAM   COUPMASS1
   69-        PARAM   K6ROT   1.0
   70-        PARAM   LGDISP  1
   71-        PARAM   LOOPID  2
   72-        PARAM   MAXLP   7
   73-        PARAM   SLOOPID 1
   74-        PARAM   STIME   0.000350
   75-        PARAM   W4      1.616E+3
   76-        PLOAD2  71      3.2E+4  213
   77-        PLOAD2  81      2.5E+4  207     208     209     212     214
   78-        PLOAD2  91      2.5E+4  217     218     219
   79-        PSHELL  200     65      0.8     65              65
   80-        SPC1    200     123456  20000   20001   20002   20003   20004   20005
   81-        SPC1    200     123456  20000   20100   20200   20300   20400   20500
   82-        SPC1    200     123456  20005   20105   20205   20305   20405   20505
   83-        SPC1    200     123456  20500   20501   20502   20503   20504   20505
   84-        TABLED1 22                                                              +NEXT1
   85-        +NEXT1  -1.     0.0     0.0     -0.0010 0.0001  -1.0    0.0002  -0.0010 +NEXT2
   86-        +NEXT2  0.004   -0.001  ENDT
   87-        TABLES1 40      0                                                       +TAB1
   88-        +TAB1   0.0     0.0     0.001   3.0E+4  0.025   4.0E+4  0.05    5.8E+4  +TAB2
   89-        +TAB2   0.10    6.7E+4  0.125   7.0E+4  0.2     7.5E+4  ENDT
   90-        TLOAD1  5       63              0       22
   91-        TLOAD1  6       62              0       22
   92-        TLOAD1  7       61              0       22
   93-        TSTEPNL 45      150     1.0E-6  20      AUTO            20      W       +LL1
   94-        +LL1    1.0E-7  1.0E-7  1.0E-7  20      20      10
   95-        TSTEPNL 46      200     1.0E-6  20      AUTO            20      W       +LL2
   96-        +LL2    1.0E-5  1.0E-5  1.0E-5  20      20      10
   97-        TSTEPNL 47      120     3.0E-6  20      AUTO            20      W       +LL3
   98-        +LL3    1.0E-4  1.0E-4  1.0E-4  20      20      10
              ENDDATA
        TOTAL COUNT=    99
```

SEQUENCE PROCESSOR OUTPUT

THERE ARE 36 POINTS DIVIDED INTO 1 GROUP(S).

CONNECTION DATA

ELEMENT TYPE	NUMBER	ASSEMBLY TIME(SEC)
QUAD4	25	0.55

TOTAL MATRIX ASSEMBLY TIME FOR 25 ELEMENTS IS 0.55 SECONDS.

ORIGINAL PERFORMANCE DATA

SUPER(GROUP) ID	NO. GRIDS	AV. CONNECTIVITY	C-AVERAGE	C-RMS	C-MAXIMUM	P-GROUPS	P-AVERAGE	DECOMP TIME(SECS (6.0 DOF/GRID)
0	36	7.11	6.83	7.08	8	0	0.0	0.252

RESEQUENCED PERFORMANCE DATA

SUPER(GROUP) ID	NO. GRIDS	AV. CONNECTIVITY	C-AVERAGE	C-RMS	C-MAXIMUM	P-GROUPS	P-AVERAGE	DECOMP TIME(SECS (6.0 DOF/GRID
0	36	7.11	6.56	6.82	8	0	0.0	0.236

NONLINEAR DEFORMATION WITH DYNAMIC LOADS
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

DECEMBER 1, 1983 MSC/NASTRAN 8/ 1/83 PAG

OLOAD RESULTANT

	T1	T2	T3	R1	R2	R3
1	0.0	0.0	5.1200075E+05	5.1200070E+06	-5.1200040E+06	0.0
1	0.0	0.0	1.9999980E+06	1.5199983E+07	-1.9999964E+07	0.0
1	0.0	0.0	1.1959590E+06	1.6799584E+07	-1.1999994E+07	0.0

NONLINEAR DEFORMATION WITH DYNAMIC LOADS
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

DECEMBER 1, 1983 MSC/NASTRAN 8/ 1/83 PAG

SUBCASE 1

POINT-ID = 20202

D I S P L A C E M E N T V E C T O R (SOLUTION SET)

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	-1.309556E-08	-1.309588E-08	-1.006220E-03	-8.515503E-05	8.515539E-05	-3.610102E-09
1.999556E-05	G	-1.929024E-08	-1.929013E-08	-1.765311E-03	-1.623774E-04	1.623782E-04	-1.280980E-08
3.999582E-05	G	-2.569747E-07	-2.569732E-07	-7.045378E-03	-6.886204E-04	6.886236E-04	-2.255902E-07
5.999569E-05	G	-2.977049E-06	-2.977031E-06	-2.124679E-02	-2.070606E-03	2.070613E-03	-2.047750E-06
7.999555E-05	G	-1.907861E-05	-1.907849E-05	-4.860260E-02	-4.710563E-03	4.710536E-03	-1.049963E-05
9.999941E-05	G	-9.057687E-05	-9.057634E-05	-9.324241E-02	-9.536058E-03	9.535693E-03	-4.447537E-05
1.199953E-04	G	-3.005541E-04	-3.005946E-04	-1.578575E-01	-1.675219E-02	1.675042E-02	-1.053858E-04
1.399591E-04	G	-7.171214E-04	-7.171298E-04	-2.352703E-01	-2.568461E-02	2.567673E-02	-3.417877E-04
1.499951E-04	G	-1.001434E-03	-1.001438E-03	-2.848293E-01	-3.056275E-02	3.054510E-02	-4.565160E-04
1.699959E-04	G	-1.775076E-03	-1.775068E-03	-3.824539E-01	-4.072147E-02	4.068851E-02	-6.237757E-04
1.899997E-04	G	-2.868215E-03	-2.868201E-03	-4.852991E-01	-5.105691E-02	5.099134E-02	-1.295286E-03
2.099956E-04	G	-4.228637E-03	-4.228611E-03	-5.886124E-01	-6.107296E-02	6.096038E-02	-1.853290E-03
2.299994E-04	G	-5.777486E-03	-5.777445E-03	-6.855155E-01	-7.056487E-02	7.039094E-02	-2.485603E-03
2.499582E-04	G	-7.403139E-03	-7.403398E-03	-7.888168E-01	-7.951162E-02	7.926291E-02	-3.158072E-03
2.699937E-04	G	-9.023014E-03	-9.023018E-03	-6.845885E-01	-8.782333E-02	8.748788E-02	-3.841923E-03
2.899892E-04	G	-1.060174E-02	-1.060181E-02	-5.781090E-01	-9.533674E-02	9.490732E-02	-4.454337E-03
3.099847E-04	G	-1.213829E-02	-1.213825E-02	-1.067886E+00	-1.018891E-01	1.013645E-01	-5.305165E-03
3.299802E-04	G	-1.364212E-02	-1.364161E-02	-1.154077E+00	-1.074188E-01	1.068043E-01	-5.650139E-03
3.499757E-04	G	-1.512610E-02	-1.512549E-02	-1.236487E+00	-1.119051E-01	1.112103E-01	-6.245486E-03
4.099957E-04	G	1.573443E-02	-1.573537E-02	-1.460734E+00	-1.203797E-01	-1.195112E-01	7.220477E-03
4.699915E-04	G	2.400838E-02	-2.400950E-02	-1.647817E+00	-1.236116E-01	-1.226704E-01	7.621430E-03
5.299873E-04	G	2.809787E-02	-2.809906E-02	-1.754744E+00	-1.230865E-01	-1.221573E-01	7.561816E-03
5.899831E-04	G	3.163867E-02	-3.164117E-02	-1.859274E+00	-1.216657E-01	-1.207693E-01	7.355479E-03
6.499789E-04	G	3.441964E-02	-3.442357E-02	-1.958665E+00	-1.202366E-01	-1.193725E-01	7.197686E-03
7.099747E-04	G	3.559757E-02	-3.560378E-02	-1.970887E+00	-1.188642E-01	-1.180274E-01	7.046532E-03

NONLINEAR DEFORMATION WITH DYNAMIC LOADS   DECEMBER   1, 1983 MSC/NASTRAN 8/ 1/83   PAG
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

SUBCASE 1

POINT-ID =   20203

D I S P L A C E M E N T   V E C T O R   (SOLUTION SET)

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	1.309551E-08	-1.309550E-08	-1.006221E-03	-8.515510E-05	-8.515512E-05	3.610230E-09
1.999996E-05	G	1.929016E-08	-1.929016E-08	-1.765312E-03	-1.623775E-04	-1.623776E-04	1.288356E-08
3.999982E-05	G	2.565733E-07	-2.569734E-07	-7.045378E-03	-6.886208E-04	-6.886211E-04	2.651710E-07
5.999969E-05	G	2.977032E-06	-2.977033E-06	-2.124680E-02	-2.070608E-03	-2.070604E-03	2.089123E-06
7.999955E-05	G	1.907851E-05	-1.907852E-05	-4.860262E-02	-4.710566E-03	-4.710518E-03	1.658013E-05
9.999941E-05	G	9.057645E-05	-9.057648E-05	-9.324247E-02	-9.536069E-03	-9.535652E-03	4.480603E-05
1.199993E-04	G	3.005953E-04	-3.005932E-04	-1.578580E-01	-1.675262E-02	-1.674593E-02	1.701248E-04
1.399991E-04	G	7.171315E-04	-7.171186E-04	-2.352705E-01	-2.568490E-02	-2.567632E-02	3.653165E-04
1.499991E-04	G	1.001441E-03	-1.001430E-03	-2.848296E-01	-3.056298E-02	-3.054673E-02	4.709717E-04
1.699959E-04	G	1.775075E-03	-1.775067E-03	-3.824943E-01	-4.072164E-02	-4.066814E-02	6.275565E-04
1.899997E-04	G	2.868210E-03	-2.868155E-03	-4.852997E-01	-5.105704E-02	-5.093104E-02	1.300931E-03
2.099596E-04	G	4.228637E-03	-4.228618E-03	-5.886131E-01	-6.107307E-02	-6.095552E-02	1.866955E-03
2.299994E-04	G	5.777434E-03	-5.777448E-03	-6.899164E-01	-7.056487E-02	-7.035016E-02	2.466378E-03
2.499982E-04	G	7.403132E-03	-7.403051E-03	-7.888180E-01	-7.951200E-02	-7.926190E-02	3.154668E-03
2.699537E-04	G	9.023108E-03	-9.023067E-03	-8.849896E-01	-8.782452E-02	-8.748752E-02	3.655462E-03
2.899892E-04	G	1.060230E-02	-1.060212E-02	-9.781069E-01	-9.533843E-02	-9.490710E-02	4.606417E-03
3.099847E-04	G	1.213865E-02	-1.213863E-02	-1.067883E+00	-1.018921E-01	-1.013651E-01	5.056594E-03
3.299802E-04	G	1.364233E-02	-1.364219E-02	-1.154074E+00	-1.074229E-01	-1.068052E-01	5.620535E-03
3.499757E-04	G	1.512870E-02	-1.512588E-02	-1.236485E+00	-1.119014E-01	-1.112036E-01	6.240458E-03
4.099957E-04	G	-1.973164E-02	-1.973068E-02	-1.460717E+00	-1.203529E-01	1.194686E-01	-7.213391E-03
4.699915E-04	G	-2.400565E-02	-2.400906E-02	-1.647821E+00	-1.236227E-01	1.226858E-01	-7.355041E-03
5.299873E-04	G	-2.809680E-02	-2.809627E-02	-1.754744E+00	-1.230774E-01	1.221518E-01	-7.370673E-03
5.899831E-04	G	-3.165168E-02	-3.165427E-02	-1.899271E+00	-1.216636E-01	1.207721E-01	-7.335855E-03
6.499789E-04	G	-3.445033E-02	-3.446028E-02	-1.958598E+00	-1.202736E-01	1.194120E-01	-7.156722E-03
7.099747E-04	G	-3.563830E-02	-3.565654E-02	-1.970733E+00	-1.189378E-01	1.183581E-01	-7.066417E-03

SUBCASE 1

POINT-ID = 20204

D I S P L A C E M E N T V E C T O R (SOLUTION SET)

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	-3.861018E-10	3.354117E-09	-4.307439E-04	-4.009833E-05	-1.626290E-04	8.066315E-06
1.999996E-05	G	-2.843338E-09	4.739150E-09	-7.171116E-04	-5.981032E-05	-2.821058E-04	5.225636E-05
3.999982E-05	G	-8.941078E-08	6.443997E-08	-2.721160E-03	-2.097688E-04	-1.111483E-03	7.827451E-04
5.999969E-05	G	-1.055426E-06	7.523902E-07	-8.205380E-03	-6.713732E-04	-3.348417E-03	5.000857E-03
7.999955E-05	G	-6.227260E-06	5.251653E-06	-1.895364E-02	-1.830019E-03	-7.613108E-03	4.831172E-02
9.999941E-05	G	-2.545752E-05	2.024751E-05	-3.682373E-02	-4.553746E-03	-1.425056E-02	1.135242E-01
1.199993E-04	G	-8.293060E-05	4.316444E-05	-6.277895E-02	-9.274002E-03	-2.475604E-02	1.456141E-01
1.399991E-04	G	-2.359756E-04	4.159380E-05	-9.560019E-02	-1.502757E-02	-3.669534E-02	1.455695E-01
1.499951E-04	G	-3.522108E-04	7.124661E-05	-1.140165E-01	-1.799502E-02	-4.713706E-02	1.424847E-01
1.699999E-04	G	-6.294420E-04	1.891348E-04	-1.536162E-01	-2.376115E-02	-6.532246E-02	1.224120E-01
1.899997E-04	G	-8.977256E-04	3.340624E-04	-1.955073E-01	-2.889533E-02	-8.515854E-02	9.755055E-02
2.099996E-04	G	-1.266548E-03	4.313150E-04	-2.379193E-01	-3.314402E-02	-1.056551E-01	7.237870E-02
2.299994E-04	G	-1.812826E-03	5.009584E-04	-2.795285E-01	-3.639502E-02	-1.261861E-01	4.805879E-02
2.499982E-04	G	-2.512052E-03	5.858706E-04	-3.214797E-01	-3.866248E-02	-1.465656E-01	2.483505E-02
2.699937E-04	G	-3.309010E-03	7.068124E-04	-3.626095E-01	-4.000124E-02	-1.667093E-01	3.140097E-03
2.899892E-04	G	-4.118256E-03	8.720448E-04	-4.033708E-01	-4.048547E-02	-1.865513E-01	-1.847105E-02
3.099847E-04	G	-4.846875E-03	1.044354E-03	-4.437796E-01	-4.024039E-02	-2.060533E-01	-3.672421E-02
3.299802E-04	G	-5.445653E-03	1.122740E-03	-4.837968E-01	-3.937636E-02	-2.251359E-01	-5.601048E-02
3.499757E-04	G	-5.522124E-03	1.107472E-03	-5.233120E-01	-3.793520E-02	-2.437507E-01	-7.346516E-02
4.099957E-04	G	-6.504644E-03	9.666872E-04	-6.366070E-01	-2.998529E-02	-2.960592E-01	-1.216174E-01
4.699915E-04	G	-6.121255E-03	9.955370E-04	-7.363382E-01	-1.534412E-02	-3.415054E-01	-1.750937E-01
5.299873E-04	G	-4.694505E-03	1.040844E-03	-8.181046E-01	1.709104E-03	-3.785549E-01	-2.214937E-01
5.899831E-04	G	-2.671463E-03	6.953555E-04	-8.765161E-01	1.822432E-02	-4.050148E-01	-2.592487E-01
6.499789E-04	G	-7.915869E-04	2.000367E-04	-9.104553E-01	3.170664E-02	-4.232405E-01	-2.516163E-01
7.099747E-04	G	3.801058E-04	-1.623641E-04	-9.187434E-01	4.029765E-02	-4.241605E-01	-3.207855E-01

NONLINEAR DEFORMATION WITH DYNAMIC LOADS DECEMBER 1, 1983 MSC/NASTRAN 8/ 1/83 PAG
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

SUBCASE 1

POINT-ID = 20304

D I S P L A C E M E N T V E C T O R (SOLUTION SET)

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	-3.861014E-10	-3.354116E-09	-4.307439E-04	4.009833E-05	-1.626250E-04	-8.066314E-06
1.999996E-05	G	-2.843338E-09	-4.739146E-09	-7.171116E-04	5.981032E-05	-2.821058E-04	-5.225642E-05
[illegible]	G	-8.941072E-08	-6.443997E-08	-2.721160E-03	2.097688E-04	-1.111484E-03	-7.827494E-04
[illegible]	G	-1.059426E-06	-7.923858E-07	-6.205380E-03	6.713732E-04	-3.346418E-03	-5.000901E-03
[illegible]	G	-6.227216E-06	-5.231651E-06	-1.858364E-02	1.833018E-03	-7.613108E-03	-4.831174E-02
[illegible]	G	-2.545751E-05	-2.024749E-05	-3.682373E-02	4.553746E-03	-1.429056E-02	-1.135244E-01
1.199993E-04	G	-8.293148E-05	-4.316564E-05	-6.277895E-02	9.274125E-03	-2.475600E-02	-1.456252E-01
1.399991E-04	G	-2.359812E-04	-4.159738E-05	-9.560019E-02	1.502783E-02	-3.889525E-02	-1.455606E-01
[illegible]	G	-3.522164E-04	-7.124715E-05	-1.140165E-01	1.799531E-02	-4.713655E-02	-1.424921E-01
[illegible]	G	-6.294453E-04	-1.891333E-04	-1.536161E-01	2.376156E-02	-6.532234E-02	-1.224233E-01
[illegible]	G	-8.977221E-04	-3.340589E-04	-1.955072E-01	2.889577E-02	-8.515682E-02	-5.758306E-02
[illegible]	G	-1.266555E-03	-4.313120E-04	-2.379190E-01	3.314452E-02	-1.056545E-01	-7.234315E-02
[illegible]	G	-1.812644E-03	-5.009538E-04	-2.755283E-01	3.639551E-02	-1.261858E-01	-4.800590E-02
[illegible]	G	-2.512119E-03	-5.858610E-04	-3.214793E-01	3.866290E-02	-1.465653E-01	-2.450348E-02
[illegible]	G	-3.309066E-03	-7.068100E-04	-3.626089E-01	4.030037E-02	-1.667101E-01	-2.866455E-03
[illegible]	G	-4.118652E-03	-8.723949E-04	-4.033697E-01	4.049593E-02	-1.865514E-01	1.663055E-02
[illegible]	G	-4.847437E-03	-1.044018E-03	-4.437793E-01	4.025080E-02	-2.060534E-01	3.774525E-02
[illegible]	G	-5.445927E-03	-1.122157E-03	-4.837976E-01	3.938377E-02	-2.251399E-01	5.555533E-02
[illegible]	G	-5.921674E-03	-1.107157E-03	-5.233133E-01	3.794428E-02	-2.437539E-01	7.336316E-02
[illegible]	G	-6.504167E-03	-9.676227E-04	-6.366007E-01	3.003111E-02	-2.960236E-01	1.244000E-01
[illegible]	G	-6.114530E-03	-9.588879E-04	-7.363393E-01	1.543238E-02	-3.415408E-01	1.687284E-01
[illegible]	G	-4.686537E-03	-1.046592E-03	-8.181040E-01	-1.628005E-03	-3.785425E-01	2.227064E-01
[illegible]	G	-2.652001E-03	-7.122753E-04	-8.765174E-01	-1.816308E-02	-4.050142E-01	2.604645E-01
[illegible]	G	-7.743663E-04	-2.285349E-04	-9.104224E-01	-3.165410E-02	-4.202245E-01	2.524852E-01
7.099747E-04	G	3.780446E-04	1.347903E-04	-9.186020E-01	-4.031100E-02	-4.240840E-01	3.152867E-01

NONLINEAR DEFORMATION WITH DYNAMIC LOADS
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

SUBCASE 1

POINT-ID = 20404

D I S P L A C E M E N T V E C T O R (SOLUTION SET)

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	-7.307162E-09	-7.307182E-09	-1.778365E-04	6.907179E-05	-6.907179E-C5	-2.383796E-09
1.999996E-C5	G	-9.128264E-09	-9.128264E-09	-3.106957E-04	1.176678E-04	-1.176678E-C4	-6.837055E-09
3.999982E-C5	G	-8.778778E-08	-8.778764E-08	-1.210744E-03	4.536253E-04	-4.536253E-C4	-9.981989E-08
5.999969E-05	G	-1.116230E-06	-1.116231E-06	-3.585843E-03	1.359913E-03	-1.359512E-C3	-8.557296E-07
7.999955E-C5	G	-7.830182E-C6	-7.830185E-06	-8.103125E-03	3.117691E-03	-3.117676E-C3	-4.762706E-06
9.999941E-C5	G	-3.445505E-05	-3.445506E-05	-1.547388E-02	6.018531E-03	-6.018426E-C3	-1.754949E-05
1.199993E-C4	G	-1.081473E-04	-1.081476E-04	-2.615156E-02	1.045239E-02	-1.045180E-C2	-5.557725E-05
1.399991E-C4	G	-2.863355E-04	-2.863409E-04	-3.541396E-02	1.632967E-02	-1.632744E-C2	-1.151713E-04
1.499991E-04	G	-4.219066E-04	-4.219071E-04	-4.671483E-02	1.972357E-02	-1.571571E-C2	-1.545440E-04
1.699959E-C4	G	-8.416325E-04	-6.416316E-04	-6.213814E-02	2.714634E-02	-2.713644E-C2	-3.640645E-04
1.899997E-C4	G	-1.425270E-03	-1.425265E-03	-7.815003E-02	3.513940E-02	-3.511800E-02	-6.005759E-04
2.099996E-C4	G	-1.919351E-03	-1.919350E-03	-9.438336E-02	4.336327E-02	-4.332319E-C2	-9.461674E-04
2.299994E-C4	G	-2.352710E-03	-2.352710E-03	-1.106641E-01	5.162245E-02	-5.155481E-C2	-1.340648E-03
2.499982E-04	G	-2.803146E-03	-2.803140E-03	-1.272734E-01	5.991480E-02	-5.580899E-02	-1.735474E-03
2.699537E-C4	G	-3.345523E-03	-3.345910E-03	-1.443066E-01	6.825256E-02	-6.809634E-C2	-2.261853E-03
2.899892E-04	G	-4.000049E-03	-3.999874E-03	-1.617091E-01	7.665169E-02	-7.642943E-C2	-3.157497E-03
3.099847E-C4	G	-4.707455E-03	-4.707050E-03	-1.793548E-01	8.510095E-02	-8.479643E-C2	-3.671924E-03
3.299802E-C4	G	-5.389225E-C3	-5.388871E-03	-1.970980E-01	9.355217E-02	-9.314728E-C2	-4.353461E-03
3.499757E-C4	G	-5.970746E-03	-5.970675E-03	-2.148190E-01	1.019932E-01	-1.014714E-C1	-4.544718E-03
4.099557E-C4	G	-7.175285E-03	-7.174693E-03	-2.677276E-01	1.265939E-01	-1.259659E-C1	-7.766651E-03
4.699515E-04	G	-8.326155E-03	-8.322433E-03	-3.183766E-01	1.502192E-01	-1.485546E-C1	-1.151702E-02
5.299873E-C4	G	-9.569553E-03	-9.564634E-03	-3.556615E-01	1.696265E-01	-1.672405E-C1	-1.418314E-02
5.899831E-C4	G	-1.033555E-02	-1.C33506E-02	-3.896124E-01	1.839871E-01	-1.805461E-C1	-1.681467E-02
6.499789E-04	G	-1.041530E-C2	-1.041065E-C2	-4.073208E-01	1.925722E-01	-1.890959E-C1	-1.638102E-02
7.099747E-C4	G	-1.020747E-02	-1.020415E-02	-4.115653E-01	1.948626E-01	-1.912603E-C1	-1.855474E-02

SUBCASE 1

ELEMENT-ID = 213

N O N L I N E A R S T R E S S E S I N Q U A D R I L A T E R A L E L E M E N T S (Q U A D 4)

TIME	FIBRE DISTANCE	STRESSES/ TOTAL STRAINS X	Y	Z	XY	EQUIVALENT STRESS	EFF. PLASTIC STRAIN	E
0.0	-3.999997E-01	7.301804E+02	7.301807E+02		-3.357143E-05	7.301807E+02	0.0	0.
		1.703753E-05	1.703754E-05		-2.909521E-12			
	3.999997E-01	-7.296191E+02	-7.296194E+02		3.359115E-05	7.296194E+02	0.0	0.
		-1.702443E-05	-1.702445E-05		2.911225E-12			
2.000E-05	-3.999997E-01	1.392219E+03	1.392219E+03		-1.259042E-04	1.392215E+03	0.0	0.
		3.246510E-05	3.246511E-05		-1.091169E-11			
	3.999997E-01	-1.391392E+03	-1.391393E+03		1.259555E-04	1.391393E+03	0.0	0.
		-3.246580E-05	-3.246582E-05		1.091613E-11			
4.000E-05	-3.999997E-01	5.907965E+03	5.907965E+03		-6.708305E-04	5.907965E+03	0.0	0.
		1.378525E-04	1.378525E-04		-5.813858E-11			
	3.999997E-01	-5.856549E+03	-5.856549E+03		6.724217E-04	5.896949E+03	0.0	0.
		-1.375955E-04	-1.375955E-04		5.827647E-11			
6.000E-05	-3.999997E-01	1.781180E+04	1.781181E+04		-2.273619E-03	1.781180E+04	0.0	0.
		4.156085E-04	4.156088E-04		-1.970468E-10			
	3.999997E-01	-1.768422E+04	-1.768422E+04		2.293437E-03	1.768422E+04	0.0	0.
		-4.126315E-04	-4.126315E-04		1.987644E-10			
8.000E-05	-3.999997E-01	2.628589E+04	2.628589E+04		-2.318915E-03	2.628585E+04	6.766084E-04	0.
		9.516410E-04	9.516412E-04		-3.676430E-10			
	3.999997E-01	-2.627007E+04	-2.627008E+04		2.451745E-03	2.627008E+04	6.391893E-04	0.
		-9.325626E-04	-9.325629E-04		3.774123E-10			
1.000E-04	-3.999997E-01	2.711526E+04	2.711526E+04		8.361537E-04	2.711526E+04	2.639452E-03	0.
		1.952415E-03	1.952414E-03		-3.552683E-10			
	3.999997E-01	-2.704020E+04	-2.704020E+04		-5.992353E-04	2.704020E+04	2.461802E-03	0.
		-1.861838E-03	-1.861838E-03		3.897882E-10			
1.200E-04	-3.999997E-01	2.839807E+04	2.839804E+04		1.148557E-02	2.839805E+04	5.675387E-03	0.
		3.500316E-03	3.500311E-03		6.553476E-10			
	3.999997E-01	-2.814896E+04	-2.814892E+04		-1.370062E-02	2.814894E+04	5.085822E-03	0.
		-3.199722E-03	-3.199717E-03		-8.347030E-10			
1.400E-04	-3.999997E-01	3.005018E+04	3.005010E+04		-3.511770E-03	3.005014E+04	9.585332E-03	0.
		5.493942E-03	5.493823E-03		8.569387E-10			
	3.999997E-01	-2.945588E+04	-2.945579E+04		4.672594E-03	2.945584E+04	6.176815E-03	0.
		-4.776716E-03	-4.776698E-03		-1.006087E-09			
1.500E-04	-3.999997E-01	3.088045E+04	3.088036E+04		9.095740E-03	3.088040E+04	1.155028E-02	0.
		6.495552E-03	6.495666E-03		2.216340E-09			
	3.999997E-01	-3.007635E+04	-3.007624E+04		-6.512772E-03	3.007629E+04	9.647232E-03	0.
		-5.525406E-03	-5.525380E-03		-1.881585E-09			
1.700E-04	-3.999997E-01	3.297669E+04	3.297658E+04		-4.454206E-04	3.297663E+04	1.351137E-02	0.
		9.025160E-03	9.025108E-03		2.660265E-09			
	3.999997E-01	-3.150566E+04	-3.150551E+04		-2.940494E-03	3.150558E+04	1.302988E-02	0.
		-7.250089E-03	-7.250041E-03		-2.555163E-09			
1.900E-04	-3.999997E-01	3.513729E+04	3.513717E+04		-2.539005E-01	3.513723E+04	2.162478E-02	0.
		1.163229E-02	1.163222E-02		-1.634441E-09			
	3.999997E-01	-3.276035E+04	-3.276018E+04		2.454577E-01	3.276027E+04	1.595531E-02	0.
		-8.764088E-03	-8.764017E-03		5.071051E-09			
2.100E-04	-3.999997E-01	3.832964E+04	3.832952E+04		-7.947141E-02	3.832958E+04	2.082455E-02	0.
		1.430630E-02	1.430620E-02		6.680740E-09			
	3.999997E-01	-3.384895E+04	-3.384879E+04		4.305864E-02	3.384886E+04	1.857565E-02	0.
		-1.007767E-02	-1.007758E-02		-1.410067E-08			
2.300E-04	-3.999997E-01	4.212427E+04	4.212427E+04		2.098348E-01	4.212427E+04	3.196846E-02	0.
		1.696680E-02	1.696669E-02		4.677917E-08			
	3.999997E-01	-3.477014E+04	-3.477012E+04		-2.184750E-01	3.477013E+04	2.075598E-02	0.
		-1.118333E-02	-1.118924E-02		-4.858615E-08			

2.500E-04	-3.999997E-01	4.581433E+04	4.581449E+04	-1.027277E-01	4.581441E+04	3.697065E-02	0.
		1.955359E-02	1.955389E-02	4.105355E-08			
	3.999997E-01	-3.556690E+04	-3.556709E+04	3.550568E-02	3.556695E+04	2.264169E-02	0.
		-1.215387E-02	-1.215079E-02	-4.235595E-08			
2.700E-04	-3.999997E-01	4.931596E+04	4.931614E+04	-1.212963E+00	4.931605E+04	4.171731E-02	0.
		2.200903E-02	2.200893E-02	-1.435872E-07			
	3.999997E-01	-3.644605E+04	-3.644627E+04	1.226376E+00	3.644614E+04	2.427146E-02	0.
		-1.258596E-02	-1.298588E-02	9.483091E-08			
2.900E-04	-3.999997E-01	5.255794E+04	5.255939E+04	3.617944E+00	5.255866E+04	4.611285E-02	0.
		2.428241E-02	2.428240E-02	-3.793725E-07			
	3.999997E-01	-3.743588E+04	-3.743759E+04	-3.700275E+00	3.743674E+04	2.561425E-02	0.
		-1.368042E-02	-1.368043E-02	-6.346517E-08			
3.100E-04	-3.999997E-01	5.437644E+04	5.437644E+04	3.097681E-01	5.437644E+04	5.014544E-02	0.
		2.634230E-02	2.634230E-02	-6.245576E-07			
	3.999997E-01	-3.818228E+04	-3.818409E+04	-1.630939E+00	3.818315E+04	2.662610E-02	0.
		-1.420373E-02	-1.420380E-02	6.664769E-08			
3.300E-04	-3.999997E-01	5.503631E+04	5.503809E+04	-2.297571E+00	5.503720E+04	5.375431E-02	0.
		2.818206E-02	2.818225E-02	-7.416487E-07			
	3.999997E-01	-3.866045E+04	-3.866504E+04	2.229605E+00	3.866275E+04	2.727617E-02	0.
		-1.453585E-02	-1.454013E-02	3.193149E-07			
3.500E-04	-3.999997E-01	5.561367E+04	5.562100E+04	1.787202E+01	5.561984E+04	5.701181E-02	0.
		2.980435E-02	2.980465E-02	9.000790E-07			
	3.999997E-01	-3.885774E+04	-3.886326E+04	-1.422128E+01	3.886051E+04	2.754425E-02	0.
		-1.467346E-02	-1.467882E-02	-1.043025E-06			
4.100E-04	-3.999997E-01	5.704087E+04	5.704438E+04	-8.908911E+01	5.704283E+04	6.486582E-02	0.
		3.376649E-02	3.376729E-02	-6.857958E-06			
	3.999997E-01	-9.216394E+03	-9.226957E+03	2.958787E+01	9.222076E+03	2.763745E-02	0.
		-1.403343E-02	-1.403395E-02	2.775856E-06			
4.700E-04	-3.999997E-01	5.803328E+04	5.804485E+04	3.763325E+01	5.803910E+04	7.037145E-02	0.
		3.654014E-02	3.654178E-02	2.190323E-06			
	3.999997E-01	3.947465E+04	3.946447E+04	-3.198914E+01	3.946962E+04	2.836993E-02	0.
		-1.253395E-02	-1.253166E-02	-2.858178E-06			
5.300E-04	-3.999997E-01	5.873888E+04	5.873244E+04	-1.922185E+01	5.873567E+04	7.421803E-02	0.
		3.847986E-02	3.848117E-02	-3.203752E-06			
	3.999997E-01	4.252861E+04	4.254070E+04	1.416665E+01	4.253466E+04	3.252477E-02	0.
		-1.038243E-02	-1.038229E-02	-1.281597E-07			
5.900E-04	-3.999997E-01	5.926381E+04	5.928276E+04	6.578966E+01	5.927340E+04	7.718748E-02	0.
		3.957644E-02	3.997912E-02	6.188371E-06			
	3.999997E-01	4.546106E+04	4.545973E+04	3.338766E+01	4.546043E+04	3.649081E-02	0.
		-8.331217E-03	-8.330930E-03	6.200292E-06			
6.500E-04	-3.999997E-01	5.966343E+04	5.968612E+04	1.631501E+02	5.967545E+04	7.940769E-02	0.
		4.105556E-02	4.109893E-02	2.570583E-05			
	3.999997E-01	4.764576E+04	4.784296E+04	1.345622E+01	4.764437E+04	3.972236E-02	0.
		-6.660365E-03	-6.658568E-03	9.833152E-06			
7.100E-04	-3.999997E-01	5.875854E+04	5.882013E+04	2.532416E+02	5.881098E+04	8.010060E-02	0.
		4.142173E-02	4.142530E-02	4.094638E-05			
	3.999997E-01	4.906304E+04	4.907562E+04	-9.681922E+00	4.906784E+04	4.138084E-02	0.
		-5.803153E-03	-5.800605E-03	1.060768E-05			

POINT-ID = 20000 SUBCASE 1

F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	7.307172E-09	7.307175E-09	-1.778367E-04	-6.907164E-05	6.507184E-05	-2.352754E-09
1.999996E-05	G	9.128257E-09	9.128264E-09	-3.106955E-04	-1.176678E-04	1.176679E-04	-6.905325E-09
3.999982E-05	G	8.778755E-08	8.778801E-08	-1.210742E-03	-4.536249E-04	4.536253E-04	-1.017945E-07
5.999969E-05	G	1.116233E-06	1.116233E-06	-3.585636E-03	-1.359512E-03	1.359512E-03	-9.312622E-07
7.999955E-05	G	7.830158E-06	7.830200E-06	-8.103110E-03	-3.117688E-03	3.117677E-03	-4.897440E-06
9.999941E-05	G	3.445511E-05	3.445511E-05	-1.547385E-02	-6.018527E-03	6.018426E-03	-1.800329E-05
1.199993E-04	G	1.081474E-04	1.081477E-04	-2.613152E-02	-1.045239E-02	1.045179E-02	-6.357872E-05
1.399991E-04	G	2.863353E-04	2.863407E-04	-3.941391E-02	-1.632970E-02	1.632740E-02	-1.164453E-04
1.499991E-04	G	4.219064E-04	4.219066E-04	-4.671475E-02	-1.972361E-02	1.971566E-02	-1.575374E-04
1.699999E-04	G	8.416323E-04	8.416316E-04	-6.213808E-02	-2.714040E-02	2.713635E-02	-3.671329E-04
1.899967E-04	G	1.425273E-03	1.425269E-03	-7.818997E-02	-3.513550E-02	3.511787E-02	-5.891566E-04
2.099996E-04	G	1.919341E-03	1.919352E-03	-9.438330E-02	-4.336337E-02	4.332304E-02	-9.577691E-04
2.299994E-04	G	2.352711E-03	2.352713E-03	-1.106641E-01	-5.162259E-02	5.155464E-02	-1.357523E-03
2.499982E-04	G	2.803149E-03	2.803142E-03	-1.272734E-01	-5.991494E-02	5.980681E-02	-1.717639E-03
2.699937E-04	G	3.345925E-03	3.345513E-03	-1.443066E-01	-6.825208E-02	6.809616E-02	-2.241032E-03
2.899892E-04	G	4.000060E-03	3.999870E-03	-1.617090E-01	-7.665169E-02	7.642537E-02	-3.158835E-03
3.099847E-04	G	4.707467E-03	4.707053E-03	-1.793548E-01	-8.510089E-02	8.475645E-02	-3.576455E-03
3.299802E-04	G	5.389226E-03	5.388867E-03	-1.970980E-01	-9.355235E-02	9.314710E-02	-4.384063E-03
3.499757E-04	G	5.970731E-03	5.970687E-03	-2.148190E-01	-1.019535E-01	1.014711E-01	-4.554730E-03
4.099957E-04	G	7.175304E-03	7.174775E-03	-2.677276E-01	-1.269948E-01	1.259089E-01	-7.058165E-03
4.699515E-04	G	8.325564E-03	8.322824E-03	-3.183767E-01	-1.502194E-01	1.485543E-01	-1.147597E-02
5.299873E-04	G	9.569364E-03	9.564981E-03	-3.596615E-01	-1.696271E-01	1.672403E-01	-1.412708E-02
5.899831E-04	G	1.034013E-02	1.033458E-02	-3.856123E-01	-1.839877E-01	1.809476E-01	-1.764407E-02
6.499789E-04	G	1.041670E-02	1.040961E-02	-4.073208E-01	-1.925705E-01	1.890575E-01	-1.845228E-02
7.099747E-04	G	1.020591E-02	1.020226E-02	-4.115654E-01	-1.948051E-01	1.912578E-01	-1.846058E-02

NONLINEAR DEFORMATION WITH DYNAMIC LOADS
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

DECEMBER 1, 1983 MSC/NASTRAN 8/ 1/83 PAG

SUBCASE 1

ELEMENT-ID = 208

N O N L I N E A R   S T R E S S E S   I N   Q U A D R I L A T E R A L   E L E M E N T S   (Q U A D 4)

TIME	FIBRE DISTANCE	STRESSES/ TOTAL STRAINS X	Y	Z	XY	EQUIVALENT STRESS	EFF. PLASTIC STRAIN	E
0.0	-3.999997E-01	4.856507E+02	3.795386E+02		-1.762265E-04	4.449607E+02	0.0	0.
		1.252763E-05	7.754379E-06		-1.527294E-11			
	3.999997E-01	-4.855518E+02	-3.790303E+02		1.763773E-04	4.446055E+02	0.0	0.
		-1.252276E-05	-7.740422E-06		1.528601E-11			
2.000E-05	-3.999997E-01	8.512612E+02	6.154399E+02		-2.850993E-04	7.612566E+02	0.0	0.
		2.222056E-05	1.200205E-05		-2.470857E-11			
	3.999997E-01	-8.504463E+02	-6.134517E+02		2.857831E-04	7.601804E+02	0.0	0.
		-2.221369E-05	-1.194392E-05		2.476784E-11			
4.000E-05	-3.999997E-01	3.383708E+03	2.298911E+03		-9.771626E-04	2.952596E+03	0.0	0.
		8.980115E-05	4.275327E-05		-8.468727E-11			
	3.999997E-01	-3.370668E+03	-2.265069E+03		9.873454E-04	2.976096E+03	0.0	0.
		-8.970487E-05	-4.175562E-05		8.556984E-11			
6.000E-05	-3.999997E-01	1.026872E+04	7.052281E+03		-3.996585E-03	9.057437E+03	0.0	0.
		2.717676E-04	1.323848E-04		-3.465437E-10			
	3.999997E-01	-1.014754E+04	-6.757578E+03		4.094511E-03	8.947883E+03	0.0	0.
		-2.706754E-04	-1.237772E-04		3.548573E-10			
8.000E-05	-3.999997E-01	2.355989E+04	1.655246E+04		-9.250676E-03	2.058335E+04	0.0	0.
		6.211381E-04	3.157498E-04		-8.022445E-10			
	3.999997E-01	-2.295484E+04	-1.509364E+04		9.817511E-03	2.020571E+04	0.0	0.
		-6.142247E-04	-2.735730E-04		8.504498E-10			
1.000E-04	-3.999997E-01	2.941652E+04	2.115619E+04		-6.048531E-03	2.628863E+04	6.830941E-04	0.
		1.264215E-03	5.716493E-04		-1.328735E-09			
	3.999997E-01	-2.567610E+04	-1.926054E+04		6.507680E-03	2.623204E+04	5.491700E-04	0.
		-1.226051E-03	-4.307283E-04		1.511785E-09			
1.200E-04	-3.999997E-01	2.956632E+04	2.307933E+04		-2.817023E-01	2.652504E+04	2.198739E-03	0.
		2.255900E-03	1.055579E-03		8.795797E-08			
	3.999997E-01	-3.022088E+04	-2.027549E+04		2.050071E-01	2.675221E+04	1.780224E-03	0.
		-2.171186E-03	-6.823658E-04		-6.545413E-08			
1.400E-04	-3.999997E-01	2.951215E+04	2.513157E+04		-3.144379E+00	2.783152E+04	4.334595E-03	0.
		3.673466E-03	1.838214E-03		-2.807947E-07			
	3.999997E-01	-3.052211E+04	-2.128816E+04		3.322398E+00	2.740598E+04	3.327501E-03	0.
		-3.335702E-03	-1.024802E-03		2.925271E-07			
1.500E-04	-3.999997E-01	3.005579E+04	2.616188E+04		-6.809511E-01	2.831040E+04	5.467544E-03	0.
		4.361305E-03	2.300837E-03		-5.628754E-08			
	3.999997E-01	-3.126909E+04	-2.152678E+04		7.134193E-01	2.772825E+04	4.090197E-03	0.
		-3.905767E-03	-1.191412E-03		6.664652E-08			
1.700E-04	-3.999997E-01	3.061605E+04	2.842075E+04		-3.886838E-01	2.958067E+04	8.474261E-03	0.
		6.084006E-03	3.638309E-03		-3.134445E-08			
	3.999997E-01	-3.223432E+04	-2.183985E+04		3.948091E-01	2.849627E+04	5.907848E-03	0.
		-5.251037E-03	-1.567203E-03		4.018110E-08			
1.900E-04	-3.999997E-01	3.131966E+04	3.061062E+04		-1.707724E+00	3.057123E+04	1.176525E-02	0.
		7.846658E-03	5.231079E-03		-1.713564E-07			
	3.999997E-01	-3.315591E+04	-2.170169E+04		2.106116E+00	2.919802E+04	7.568661E-03	0.
		-6.575626E-03	-1.867261E-03		1.865065E-07			
2.100E-04	-3.999997E-01	3.233545E+04	3.260668E+04		7.152608E+00	3.247192E+04	1.531687E-02	0.
		9.654235E-03	7.045303E-03		6.185927E-07			
	3.999997E-01	-3.355917E+04	-2.177318E+04		-7.022744E+00	2.982860E+04	5.061012E-03	0.
		-7.755381E-03	-2.110454E-03		-5.951065E-07			
2.300E-04	-3.999997E-01	3.334030E+04	3.466993E+04		3.796310E+00	3.402461E+04	1.895157E-02	0.
		1.144198E-02	9.003069E-03		5.643935E-07			
	3.999997E-01	-3.472760E+04	-2.167919E+04		-5.147122E+00	3.036301E+04	1.037312E-02	0.
		-8.803729E-03	-2.300215E-03		-5.341940E-07			

2.500E-04	-3.999997E-01	3.418509E+04	3.687800E+04	-2.070811E+01	3.560802E+04	2.273097E-02	0.
		1.316053E-02	1.109857E-02	-1.709931E-06			
	3.999997E-01	-3.543884E+04	-2.104560E+04	2.111043E+01	3.087067E+04	1.152725E-02	0.
		-9.751912E-03	-2.418544E-03	1.765017E-06			
2.700E-04	-3.999997E-01	3.555007E+04	4.016293E+04	8.398761E+00	3.808297E+04	2.645025E-02	0.
		1.476984E-02	1.333623E-02	5.306471E-07			
	3.999997E-01	-3.606579E+04	-2.003968E+04	-6.560416E+00	3.125830E+04	1.253532E-02	0.
		-1.061173E-02	-2.467222E-03	-4.815140E-07			
2.900E-04	-3.999997E-01	3.696496E+04	4.387848E+04	-4.893932E+01	4.086282E+04	3.025843E-02	0.
		1.624202E-02	1.572197E-02	-3.559328E-06			
	3.999997E-01	-3.655733E+04	-1.902561E+04	3.686347E+01	3.166845E+04	1.341533E-02	0.
		-1.137708E-02	-2.467325E-03	3.500097E-06			
3.100E-04	-3.999997E-01	3.828300E+04	4.756353E+04	-6.065928E+00	4.366925E+04	3.406275E-02	0.
		1.757861E-02	1.825422E-02	-1.056038E-06			
	3.999997E-01	-3.652660E+04	-1.832128E+04	1.600457E+00	3.157565E+04	1.415194E-02	0.
		-1.201150E-02	-2.447151E-03	8.574982E-07			
3.300E-04	-3.999997E-01	3.961894E+04	5.119295E+04	4.034924E+00	4.649912E+04	3.785861E-02	0.
		1.860084E-02	2.096682E-02	1.334418E-07			
	3.999997E-01	-3.720263E+04	-1.817588E+04	-6.608056E+00	3.222123E+04	1.472359E-02	0.
		-1.254101E-02	-2.433616E-03	-4.126638E-07			
3.500E-04	-3.999997E-01	4.084450E+04	5.479118E+04	-1.479797E+01	4.932512E+04	4.172961E-02	0.
		1.950391E-02	2.364065E-02	-1.854509E-06			
	3.999997E-01	-3.740573E+04	-1.909172E+04	1.853650E+01	3.239666E+04	1.513677E-02	0.
		-1.250359E-02	-2.460360E-03	1.420626E-06			
4.100E-04	-3.999997E-01	4.321699E+04	6.172862E+04	6.179595E+02	5.487761E+04	5.291303E-02	0.
		2.260885E-02	3.194254E-02	3.045764E-05			
	3.999997E-01	-3.620939E+04	-2.707240E+04	-3.564902E+02	3.262124E+04	1.567027E-02	0.
		-1.322678E-02	-2.782349E-03	-2.919893E-05			
4.700E-04	-3.999997E-01	3.984644E+04	6.490043E+04	-9.678345E+02	5.671475E+04	6.305808E-02	0.
		2.425472E-02	3.987446E-02	-6.981812E-05			
	3.999997E-01	-2.350340E+04	-3.717214E+04	7.734211E+02	3.265570E+04	1.578181E-02	0.
		-1.274967E-02	-3.290745E-03	6.962725E-05			
5.300E-04	-3.999997E-01	4.137594E+04	6.665769E+04	2.641277E+02	5.828724E+04	7.174170E-02	0.
		2.543337E-02	4.681119E-02	1.743871E-05			
	3.999997E-01	-1.137396E+03	-3.346222E+04	-2.567585E+02	3.251141E+04	1.635701E-02	0.
		-1.150779E-02	-3.981948E-03	-1.756111E-05			
5.900E-04	-3.999997E-01	4.016696E+04	6.832231E+04	2.353042E+02	5.947630E+04	7.830793E-02	0.
		2.620957E-02	5.213967E-02	2.327842E-05			
	3.999997E-01	2.051942E+04	-1.743027E+04	-2.715808E+02	3.326093E+04	1.718419E-02	0.
		-1.074128E-02	-4.461370E-03	-2.281362E-05			
6.500E-04	-3.999997E-01	4.310842E+04	6.877906E+04	1.649262E+02	6.019985E+04	8.230358E-02	0.
		2.686875E-02	5.533811E-02	1.961848E-05			
	3.999997E-01	2.935137E+04	-7.326480E+03	-9.861114E+01	3.361922E+04	1.803216E-02	0.
		-9.761259E-03	-4.838306E-03	-1.505947E-05			
7.100E-04	-3.999997E-01	4.804759E+04	6.687969E+04	-3.598267E+02	5.973647E+04	8.352023E-02	0.
		2.725049E-02	5.620308E-02	-2.363011E-05			
	3.999997E-01	2.321720E+04	-5.242441E+03	5.861702E+02	2.904182E+04	1.861354E-02	0.
		-5.370424E-03	-5.211283E-03	3.788182E-05			

NONLINEAR DEFORMATION WITH DYNAMIC LOADS
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

SUBCASE 1

POINT-ID = 20003

F O R C E S   O F   S I N G L E - P O I N T   C O N S T R A I N T

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	-7.307182E-09	7.307179E-09	-1.778365E-04	-6.907179E-05	-6.507180E-05	2.402586E-09
1.999994E-05	G	-9.128264E-09	9.128264E-09	-3.106957E-04	-1.176678E-04	-1.176678E-04	6.801446E-09
3.999982E-05	G	-8.778778E-08	8.778778E-08	-1.210744E-03	-4.536253E-04	-4.536251E-04	5.559274E-08
5.999969E-05	G	-1.116230E-06	1.116230E-06	-3.585843E-03	-1.359913E-03	-1.359912E-03	6.551969E-07
7.999955E-05	G	-7.830183E-06	7.830183E-06	-8.103125E-03	-3.117691E-03	-3.117676E-03	4.716288E-06
9.999941E-05	G	-3.445503E-05	3.445506E-05	-1.547388E-02	-6.018531E-03	-6.018426E-03	1.761346E-05
1.199993E-04	G	-1.081478E-04	1.081476E-04	-2.615156E-02	-1.045235E-02	-1.045185E-02	4.384694E-05
1.399991E-04	G	-2.863416E-04	2.863407E-04	-3.941395E-02	-1.632951E-02	-1.632760E-02	1.410263E-04
1.499991E-04	G	-4.219013E-04	4.219080E-04	-4.671482E-02	-1.972337E-02	-1.971591E-02	1.817056E-04
1.699999E-04	G	-8.416311E-04	8.416339E-04	-6.213812E-02	-2.714603E-02	-2.713674E-02	3.549636E-04
1.899997E-04	G	-1.425267E-03	1.425271E-03	-7.818997E-02	-3.513895E-02	-3.511650E-02	6.074351E-04
2.099956E-04	G	-1.919360E-03	1.919365E-03	-9.438324E-02	-4.336276E-02	-4.332376E-02	8.501135E-04
2.299994E-04	G	-2.352711E-03	2.352717E-03	-1.106640E-01	-5.162183E-02	-5.155547E-02	1.271707E-03
2.499982E-04	G	-2.803114E-03	2.803171E-03	-1.272734E-01	-5.991421E-02	-5.980560E-02	1.813054E-03
2.699937E-04	G	-3.345571E-03	3.345959E-03	-1.443067E-01	-6.825238E-02	-6.809730E-02	2.345521E-03
2.899892E-04	G	-4.000012E-03	4.000191E-03	-1.617109E-01	-7.664937E-02	-7.642543E-02	2.635528E-03
3.099847E-04	G	-4.706653E-03	4.707139E-03	-1.753581E-01	-8.509874E-02	-8.479732E-02	3.552654E-03
3.299802E-04	G	-5.388808E-03	5.389042E-03	-1.970995E-01	-9.354985E-02	-9.314560E-02	4.278462E-03
3.495757E-04	G	-5.970519E-03	5.970702E-03	-2.148190E-01	-1.013893E-01	-1.014674E-01	5.365733E-03
4.099957E-04	G	-7.183559E-03	7.182561E-03	-2.677094E-01	-1.270148E-01	-1.260083E-01	8.134175E-03
4.699915E-04	G	-8.324560E-03	8.322657E-03	-3.183878E-01	-1.532019E-01	-1.485452E-01	1.084350E-02
5.299873E-04	G	-9.572282E-03	9.570260E-03	-3.596616E-01	-1.696284E-01	-1.672453E-01	1.426765E-02
5.899831E-04	G	-1.032100E-02	1.031891E-02	-3.856143E-01	-1.839874E-01	-1.809530E-01	1.666323E-02
6.499789E-04	G	-1.036350E-02	1.036188E-02	-4.073034E-01	-1.925983E-01	-1.891245E-01	1.636867E-02
7.099747E-04	G	-1.013650E-02	1.013480E-02	-4.116728E-01	-1.949472E-01	-1.913401E-01	1.655551E-02

NONLINEAR DEFORMATION WITH DYNAMIC LOADS   DECEMBER 1, 1983 MSC/NASTRAN 8/ 1/83 PAG
TRANSIENT RESPONSE BY SHOCK WAVE LOAD.

SUBCASE 1

POINT-ID = 20005

FORCES OF SINGLE-POINT CONSTRAINT

TIME	TYPE	T1	T2	T3	R1	R2	R3
0.0	G	-1.309556E-08	-1.309580E-08	-1.006220E-03	-8.515503E-05	8.515539E-05	-3.610102E-09
1.999996E-05	G	-1.929624E-08	-1.929013E-08	-1.769311E-03	-1.623774E-04	1.623782E-04	-1.260980E-08
3.999982E-05	G	-2.569741E-07	-2.569732E-07	-7.045378E-03	-6.886204E-04	6.886234E-04	-2.259902E-07
5.999569E-05	G	-2.977649E-06	-2.977031E-06	-2.124679E-02	-2.070606E-03	2.070613E-03	-2.047750E-06
7.999955E-05	G	-1.907661E-05	-1.907849E-05	-4.860260E-02	-4.710563E-03	4.710536E-03	-1.069963E-05
9.999941E-05	G	-9.057667E-05	-9.057634E-05	-9.324241E-02	-9.536058E-03	9.535653E-03	-4.447537E-05
1.199993E-04	G	-3.005541E-04	-3.005946E-04	-1.578579E-01	-1.675219E-02	1.675042E-02	-1.053856E-04
1.399991E-04	G	-7.171214E-04	-7.171258E-04	-2.352703E-01	-2.568461E-02	2.567673E-02	-3.477877E-04
1.499991E-04	G	-1.001434E-03	-1.031438E-03	-2.848293E-01	-3.056275E-02	3.054510E-02	-4.569360E-04
1.699999E-04	G	-1.775076E-03	-1.775068E-03	-3.824939E-01	-4.072147E-02	4.068851E-02	-8.237757E-04
1.899997E-04	G	-2.668215E-03	-2.668201E-03	-4.852991E-01	-5.105691E-02	5.099134E-02	-1.295266E-03
2.099996E-04	G	-4.228637E-03	-4.228611E-03	-5.886124E-01	-6.107298E-02	6.096038E-02	-1.853250E-03
2.299994E-04	G	-5.777486E-03	-5.777445E-03	-6.855155E-01	-7.056467E-02	7.039094E-02	-2.465063E-03
2.499982E-04	G	-7.403135E-03	-7.403098E-03	-7.868168E-01	-7.951182E-02	7.926291E-02	-3.158372E-03
2.699937E-04	G	-9.023074E-03	-9.023018E-03	-8.849485E-01	-8.782333E-02	8.746768E-02	-3.841923E-03
2.899892E-04	G	-1.060174E-02	-1.060181E-02	-9.781090E-01	-9.533074E-02	9.490752E-02	-4.454337E-03
3.099847E-04	G	-1.213829E-02	-1.213825E-02	-1.067886E+00	-1.018891E-01	1.013649E-01	-5.305165E-03
3.299802E-04	G	-1.364612E-02	-1.364181E-02	-1.154077E+00	-1.074188E-01	1.068043E-01	-5.650135E-03
3.499757E-04	G	-1.512613E-02	-1.512549E-02	-1.236487E+00	-1.119031E-01	1.112133E-01	-6.245486E-03
4.099557E-04	G	-1.973164E-02	-1.973068E-02	-1.463717E+00	-1.203529E-01	1.194686E-01	-7.213351E-03
4.699915E-04	G	-2.400569E-02	-2.409066E-02	-1.647821E+00	-1.236227E-01	1.226858E-01	-7.585041E-03
5.299873E-04	G	-2.809680E-02	-2.809627E-02	-1.794744E+00	-1.230774E-01	1.221518E-01	-7.570673E-03
5.899831E-04	G	-3.165168E-02	-3.165427E-02	-1.899271E+00	-1.216636E-01	1.237721E-01	-7.335854E-03
6.499789E-04	G	-3.445053E-02	-3.446024E-02	-1.958598E+00	-1.202736E-01	1.194120E-01	-7.196728E-03
7.099747E-04	G	-3.563833E-02	-3.565654E-02	-1.970733E+00	-1.189378E-01	1.180581E-01	-7.066417E-03

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